Submitted by the task force for amending R134

Informal document **GRSP-72-17**
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agenda item 11)

Proposal for the 02 series of amendments to the UN Regulation No.134 with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV) – consolidated text

Submitted by the task force amending UN Regulation No.134

The text reproduced below was prepared by the task force involving France, Japan, the Netherlands, the European Commission, CLEPA and OICA as well as related industry experts in order to transpose the amendment 1 to UN Global Technical Regulation No. 13, Phase 2 (GTR13-PH2) into the UN regulation under the 1958 Agreement. The modifications to the existing text of the UN Regulation No, 134 are marked in bold for new or strikethrough for deleted characters.

I. Proposal

Paragraphs 1.2. to 1.3., amend to read:

"1.2. Part II - Specific components for compressed hydrogen storage systems for **hydrogen-fuelled** ~~hydrogenfuelled~~ vehicles on their safety-related performance.

1.3. Part III **Hydrogen-fuelled** ~~Hydrogenfuelled~~ vehicles of category M and N[1] incorporating compressed hydrogen storage system on its safety-related performance."

Paragraphs 2.2. to 2.4., amend to read:

"2.2. "*Check valve*" means a non-return valve that prevents reverse flow ~~in the vehicle fuel line~~.

2.3. "*Compressed hydrogen storage system (CHSS)*" means a system designed to store **compressed** hydrogen fuel for a hydrogen-fuelled vehicle and composed of a ~~pressurized~~ container, **container attachments (if any), and all primary closure devices required to** ~~pressure relief devices (PRDs) and shut off device(s) that~~ isolate the stored hydrogen from the remainder of the fuel system and ~~its~~ **the** environment.

2.4. "*Container*" (for hydrogen storage) means the **pressure-bearing** component **on the vehicle** ~~the hydrogen storage system~~ that stores the primary volume of hydrogen fuel **in a single chamber or in multiple permanently interconnected chambers**."

Insert new paragraphs 2.5., to read:

"**2.5. "Container Attachments" mean non-pressure bearing parts attached to the container that provide additional support and/or protection to the container and that may be only temporarily removed for maintenance and/or inspection only with the use of tools.**"

Renumber (former) paragraph 2.5. as new paragraph 2.6.

Renumber (former) paragraphs 2.6.to 2.7. as new paragraph 2.7. to 2.8., and amend to read:

"2.**7**~~6~~. "*Date of manufacture*" (of a compressed hydrogen container) means the date (month and year) of the proof pressure test **or final inspection test** carried out **by the manufacturer** ~~during manufacture~~.

2.**8**~~7~~. "*Enclosed or semi-enclosed spaces*" mean~~s~~ the special volumes within the vehicle (or the vehicle outline across openings) that are external to the hydrogen system (storage system, fuel cell system**, internal combustion engine (ICE)** and fuel flow management system) ~~and its housings (if any) where hydrogen may accumulate (and thereby pose a hazard)~~. "

Delete (former) paragraph 2.8.

Paragraph 2.12., amend to read:

"2.12. "*Hydrogen-fuelled vehicle*" means any motor vehicle that uses compressed gaseous hydrogen as a fuel to propel the vehicle, including fuel cell and internal combustion engine vehicles. Hydrogen fuel for ~~passenger~~ **the** vehicles is specified in **ISO 14687:2019 and SAE J2719_202003**~~ISO 14687-2: 2012 and SAE J2719: (September 2011 Revision)~~. "

Paragraphs 2.15. to 2.17., amend to read:

"2.15. "*Maximum allowable working pressure (MAWP)*" means the highest gauge pressure to which a~~ pressure~~ container or **hydrogen** storage system is permitted to operate under normal operating conditions.

2.16. "*Maximum fuelling pressure (MFP)*" means the maximum pressure applied to compressed **hydrogen storage** system during fuelling. The maximum fuelling pressure is 125 per cent of the Nominal Working Pressure.

2.17. "*Nominal working pressure (NWP)*" means the gauge pressure that characterizes typical operation of a system. For compressed hydrogen **storage system**~~ gas containers~~, NWP is the settled pressure of compressed gas in fully fuelled container ~~or storage system~~ at a uniform temperature of 15 °C. "

Insert new paragraphs 2.18., to read:

"**2.18. "*Passenger compartment*" means the space for occupant accommodation, bounded by the roof, floor, side walls, doors, outside glazing, front bulkhead and rear bulkhead or rear gate.** "

Renumber (former) paragraph 2.18. as new paragraph 2.19.

Insert new paragraphs 2.20., to read:

"**2.20. "*Rechargeable electrical energy storage system* (REESS)" means the rechargeable energy storage system that provides electric energy for electrical propulsion.** "

Renumber (former) paragraph 2.19. as new paragraph 2.21.

Delete (former) paragraph 2.20.

~~2.20. "*Safety relief valve*" means a pressure relief device that opens at a preset pressure level and can re-close.~~

Renumber (former) paragraph 2.21. as new paragraph 2.22.

Renumber (former) paragraphs 2.22.to 2.23. as new paragraphs 2.23. to 2.24., and amend to read:

"2.**23**~~22~~. "*Shut-off valve*" means a valve between the ~~storage~~ container and the vehicle fuel system that **must default**~~ can be automatically activated; which defaults~~ to the "closed" position when not connected to a power source.

2.**24**~~23~~. "*Single failure*" means a failure caused by a single event, including any consequential failures resulting from this failure. "

Insert new paragraphs 2.25. to 2.26., to read:

"**2.25. "*Specific Heat Release Rate (HRR/A)*" means the heat release from a fire per unit area of the burner where the heat release is based on the rate of fuel being combusted multiplied by the lower heating value (LHV) of the fuel. The LHV (sometimes called the Net Heating Value) is appropriate for the characterization of vehicle fires since the product water from combustion remains a vapour. The LHV is approximately 46 MJ/kg but needs to be determined at each site based on the actual LPG composition.**

2.26. “***State of charge (SOC)*” means the density ratio of hydrogen in the CHSS between the actual CHSS condition and that at NWP with the CHSS equilibrated to 15 °C. SOC is expressed as a percentage using the formula:**

$$SOC(\%) = \frac{\rho(P,T)}{\rho(NWP, 15°C)} x100$$

The density of hydrogen at different pressure and temperature are listed in the Table 1 below.

Table 1

Compressed Hydrogen Density (g/l)

Temperature (°C)	***Pressure (MPa)***												
	1	***10***	***20***	***30***	***35***	***40***	***50***	***60***	***65***	***70***	***75***	***80***	***87.5***
-40	**1.0**	**9.7**	**18.1**	**25.4**	**28.6**	**31.7**	**37.2**	**42.1**	**44.3**	**46.1**	**48.4**	**50.3**	**53.0**
-30	**1.0**	**9.4**	**17.5**	**24.5**	**27.7**	**30.6**	**36.0**	**40.8**	**43.0**	**45.1**	**47.1**	**49.0**	**51.7**
-20	**1.0**	**9.0**	**16.8**	**23.7**	**26.8**	**29.7**	**35.0**	**39.7**	**41.9**	**43.9**	**45.9**	**47.8**	**50.4**
-10	**0.9**	**8.7**	**16.2**	**22.9**	**25.9**	**28.7**	**33.9**	**38.6**	**40.7**	**42.8**	**44.7**	**46.6**	**49.2**
0	**0.9**	**8.4**	**15.7**	**22.2**	**25.1**	**27.9**	**33.0**	**37.6**	**39.7**	**41.7**	**43.6**	**45.5**	**48.1**
10	**0.9**	**8.1**	**15.2**	**21.5**	**24.4**	**27.1**	**32.1**	**36.6**	**38.7**	**40.7**	**42.6**	**44.4**	**47.0**
15	**0.8**	**7.9**	**14.9**	**21.2**	**24.0**	**26.7**	**31.7**	**36.1**	**38.2**	**40.2**	**42.1**	**43.9**	**46.5**
20	**0.8**	**7.8**	**14.7**	**20.8**	**23.7**	**26.3**	**31.2**	**35.7**	**37.7**	**39.7**	**41.6**	**43.4**	**46.0**
30	**0.8**	**7.6**	**14.3**	**20.3**	**23.0**	**25.6**	**30.4**	**34.8**	**36.8**	**38.8**	**406**	**42.4**	**45.0**
40	**0.8**	**7.3**	**13.9**	**19.7**	**22.4**	**24.9**	**29.7**	**34.0**	**36.0**	**37.9**	**39.7**	**41.5**	**44.0**
50	**0.7**	**7.1**	**13.5**	**19.2**	**21.8**	**24.3**	**28.9**	**33.2**	**35.2**	**37.1**	**38.9**	**40.6**	**43.1**
60	**0.7**	**6.9**	**13.1**	**18.7**	**21.2**	**23.7**	**28.3**	**32.4**	**34.4**	**36.3**	**38.1**	**39.8**	**42.3**
70	**0.7**	**6.7**	**12.7**	**18.2**	**20.7**	**23.1**	**27.6**	**31.7**	**33.6**	**35.5**	**37.3**	**39.0**	**41.4**
80	**0.7**	**6.5**	**12.4**	**17.7**	**20.2**	**22.6**	**27.0**	**31.0**	**32.9**	**34.7**	**36.5**	**38.2**	**40.6**
85	**0.7**	**6.4**	**12.2**	**17.5**	**20.0**	**22.3**	**26.7**	**30.7**	**32.6**	**34.4**	**36.1**	**37.8**	**40.2**

"

Renumber (former) paragraphs 2.24.to 2.28. as new paragraphs 2.27. to 2.31.

Paragraph 3.1.2., amend to read:

"3.1.2. A model of information document is shown in Annex 1, Part 1**, Model**–**I.**"

Paragraph 3.2.2., amend to read:

"3.2.2. A model of information document is shown in Annex 1, Part 1**, Model** -II."

"3.3.2. A model of information document is shown in Annex 1, Part 1**, Model** - III."

Paragraph 5., amend to read:

"5. Part I – Specifications of the compressed hydrogen storage system

This part specifies the requirements for the compressed hydrogen storage system.

(a) The primary closure devices shall include the following functions, which may be combined:

(i) TPRD;

(ii) Check valve; and

(iii) Shut-off valve

(b) **The primary closure devices shall be mounted directly on or within each container. [If needed, manufacturers may choose to locate additional TPRDs in alternative locations on the container. However, any additional TPRDs should be connected directly to the container by using supply lines that have demonstrated mechanical integrity and durability as part of qualification tests for the CHSS (i.e., pneumatic sequential test in paragraph 5.3., fire test in paragraph 5.4. and verification of closure durability in paragraph 6.1.) as well as the specific loads related to the integration of this components to the vehicle (i.e. crash, vibration).]**

(c) **The CHSS shall meet the performance test requirements summarized in Table 2. The corresponding test procedures are specified in Annex 3.**

(d) **All new compressed hydrogen storage systems produced for on-road vehicle service shall have a NWP of 70 MPa or less**.

(e) **The service life of the CHSS shall be determined by the manufacturer, who shall establish the date of removal from the service taking account of the performance requirements applied in the respective market.**

Table 2
Overview of performance requirements

Requirement section	*Test article*
5.1. Verification tests for baseline metrics	**Container or container plus container attachments, as applicable**
5.2. Verification test for performance durability	**Container or container plus container attachments, as applicable**
5.3. Verification test for expected on-road performance	**CHSS**
5.4. Verification test for service terminating performance in fire	**CHSS**

~~The hydrogen storage system consists of the high pressure storage container and primary closure devices for openings into the high pressure storage container. Figure 1 shows a typical compressed hydrogen storage system consisting of a pressurized container, three closure devices and their fittings. The closure devices shall include the following functions, which may be combined:~~

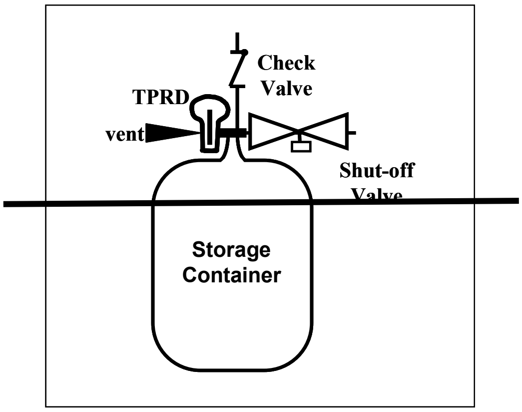
~~(a) TPRD;~~

~~(b) Check valve that prevents reverse flow to the fill line; and~~

~~(c) Automatic shut-off valve that can close to prevent flow from the container to the fuel cell or internal combustion engine. Any shut-off valve, and TPRD that form the primary closure of flow from the storage container shall be mounted directly on or within each container. At least one component with a check valve function shall be mounted directly on or within each container.~~

~~Figure 1~~

~~**Typical compressed hydrogen storage system**~~



All new compressed hydrogen storage systems produced for on-road vehicle service shall have a NWP of 70 MPa or less~~and a service life of 15 years (or upon the request of the manufacturer 20 years in case of vehicles of categories M2, M3, N2 and N3 (hereinafter referred to as "20 years")) or less, and be capable of satisfying the requirements of paragraph 5~~.

~~The hydrogen storage system shall meet the performance test requirements specified in this paragraph. The qualification requirements for on-road service are:~~

~~5.1. Verification tests for baseline metrics~~

~~5.2. Verification test for performance durability (hydraulic sequential tests)~~

~~5.3. Verification test for expected on-road system performance (pneumatic sequential tests)~~

~~5.4. Verification test for service terminating system performance in Fire~~

~~5.5. Verification test for performance durability of primary closures.~~

~~The test elements within these performance requirements are summarized in Table 1. The corresponding test procedures are specified in Annex 3.~~

~~Table 1~~

~~**Overview of performance requirements**~~

~~5.1.~~ ~~5.1.1.~~ ~~5.1.2.~~	~~Verification tests for baseline metrics~~ ~~Baseline initial burst pressure~~ ~~Baseline initial pressure cycle life~~
~~5.2.~~ ~~5.2.1.~~ ~~5.2.2.~~ ~~5.2.3.~~	~~Verification test for performance durability (sequential hydraulic tests)~~ ~~Proof pressure test~~ ~~Drop (impact) test~~

~~5.2.4.~~ ~~5.2.5.~~ ~~5.2.6.~~ ~~5.2.7.~~ ~~5.2.8.~~	~~Surface damage~~ ~~Chemical exposure and ambient temperature pressure cycling tests~~ ~~High temperature static pressure test~~ ~~Extreme temperature pressure cycling~~ ~~Residual proof pressure test~~ ~~Residual strength Burst Test~~
~~5.3.~~ ~~5.3.1.~~ ~~5.3.2.~~ ~~5.3.3.~~ ~~5.3.4.~~ ~~5.3.5.~~	~~Verification test for expected on-road performance (sequential pneumatic tests)~~ ~~Proof pressure test~~ ~~Ambient and extreme temperature gas pressure cycling test (pneumatic)~~ ~~Extreme temperature static gas pressure leak/permeation test (pneumatic)~~ ~~Residual proof pressure test~~ ~~Residual strength burst test (hydraulic)~~
~~5.4.~~	~~Verification test for service terminating performance in fire~~
~~5.5.~~	~~Requirements for primary closure devices~~

"

Paragraphs 5.1.1. to 5.4., amend to read:

"5.1.1. Baseline initial burst pressure

Three (3) containers shall be hydraulically pressurized until burst **in accordance with** ~~(~~Annex 3, paragraph 2.1.~~ test procedure).~~ **The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure.** The manufacturer shall supply documentation (measurements and statistical analyses) that establish the midpoint burst pressure of new ~~storage~~ containers, BP_O.

All containers tested shall have a burst pressure within ±10 per cent of BP_O and greater than or equal to a minimum BPmin of **200** ~~225~~ per cent NWP.

~~In addition, c~~**C**ontainers having glass-fibre composite as a primary constituent **shall** ~~to~~ have a minimum burst pressure greater than 350 per cent NWP.

5.1.2. Baseline initial pressure cycle life

Three (3) containers shall be hydraulically pressure cycled ~~at the ambient temperature of 20 (±5) °C to 125 per cent NWP (+2/-0 MPa)~~ without rupture for 22,000 cycles ~~for a 15-year service life or 30,000 cycles for a 20-year service life of vehicles of categories M_2, M_3, N_2 and N_3 (hereinafter referred to as "a 20-year service life"),~~ or until a leak occurs ~~(~~ i**n accordance with** Annex 3, paragraph 2.2. ~~test procedure).~~ **The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure.** Leakage shall not occur within 11,000 cycles ~~for a 15-year service life or 15,000 cycles for a 20-year service life~~.

5.2. Verification tests for performance durability (Hydraulic sequential tests)

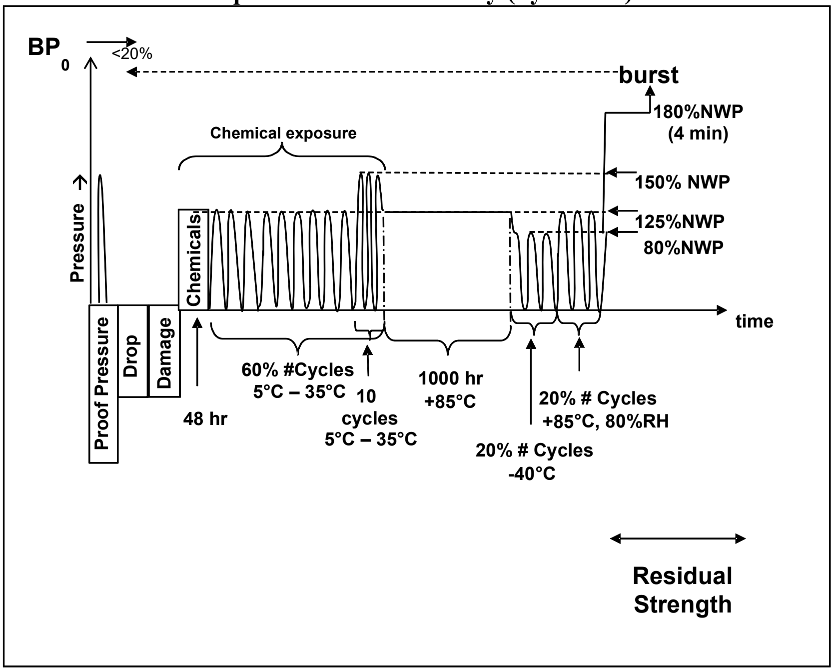
If all three pressure cycle life measurements made in paragraph 5.1.2. are greater than 11,000 cycles~~ for a 15-year service life or 15,000 cycles for a 20-year service life~~, or if they are all within ± 25 per cent of each other, then only one (1) container is tested in paragraph 5.2. Otherwise, three (3) containers are tested in paragraph 5.2.

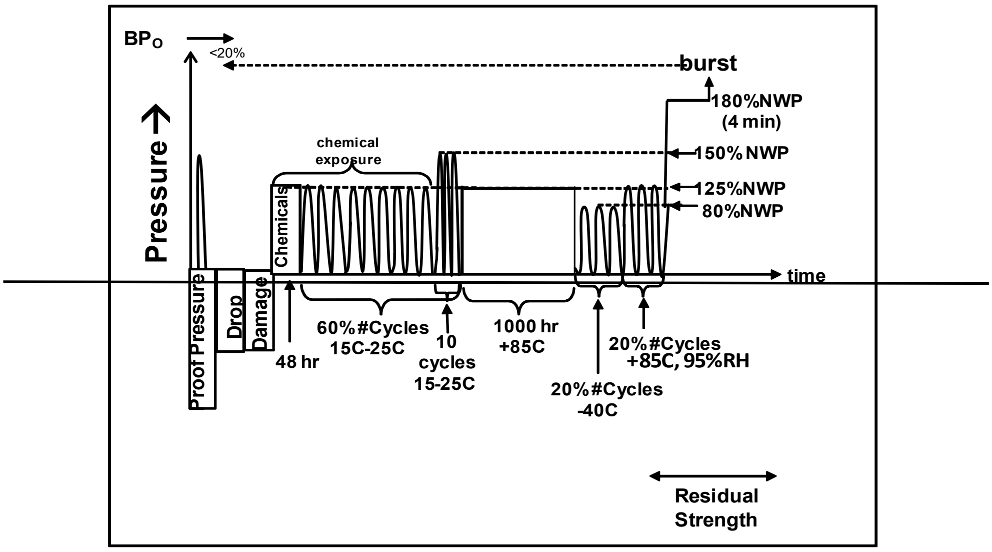
Unless otherwise specified, the tests in paragraph 5.2 shall be conducted on the container equipped with its container attachments (if any) that represents the CHSS without the primary closures.

~~A hydrogen storage~~ **The** container shall not leak during the following sequence of tests, which are applied in series to a single system and which are illustrated in Figure **1**~~2~~. Specifics of applicable test procedures~~ for the hydrogen storage system~~ are provided in Annex 3, paragraph 3.

Figure 1~~2~~

Verification test for performance durability (hydraulic)





5.2.1. Proof pressure test

~~A storage~~ **The** container is pressurized ~~to 150 per cent NWP (+2/-0 MPa) and held for at least 30 sec (~~ **in accordance with the procedure specified in** Annex 3, paragraph 3.1. ~~test procedure).~~ **The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results. and are not affected by the test procedure.** ~~A storage~~ **The container that has undergone a proof pressure test in manufacture is exempt from this test**.

5.2.2. Drop (impact) test

The~~ storage~~ container **with its container attachments (if any)** is dropped~~ at several impact angles (~~ **once in one of the impact orientations specified in paragraph** Annex 3, paragraph 3.2.~~ test procedure).~~

5.2.3. Surface damage test

The~~ storage~~ container **with its container attachments (if applicable)** is subjected to surface damage ~~(~~**specified in** Annex 3, paragraph 3.3.~~ test procedure)~~.

All-metal containers are exempt from the surface flaw generation portion of testing.

5.2.4. Chemical exposure and ambient-temperature pressure cycling test

The~~ storage~~ container **with its container attachments (if applicable)** is exposed to chemicals found in the on-road environment and pressure cycled ~~to 125 per cent NWP (+2/-0 MPa) at 20 (±5) °C for 60 per cent number of Cycles pressure cycles (~~ **in accordance with** Annex 3, paragraph 3.4.~~ test procedure). Chemical exposure is discontinued before the last 10 cycles, which are conducted to 150 per cent NWP (+2/-0 MPa).~~

5.2.5. High temperature static pressure test.

The~~ storage~~ container **with its container attachments (if applicable)** is pressurized~~ to 125 per cent NWP (+2/-0 MPa) at ≥85°C for at least 1,000 hours (~~ **in accordance with** Annex 3, paragraph 3.5. test procedure).

5.2.6. Extreme temperature pressure cycling **test**.

The~~ storage~~ container **with its container attachments (if applicable)** is pressure cycled~~ at ≤ -40 °C to 80 per cent NWP (+2/-0 MPa) for 20 per cent number of Cycles and at ≥ +85 °C and 95 (±2) per cent relative humidity to 125 per cent NWP (+2/-0 MPa) for 20 per cent number of Cycles (~~ **in accordance with** Annex 3, paragraph **3.6.**~~2.2. test procedure)~~.

5.2.7. ~~Hydraulic r~~**R**esidual **proof** pressure test.

The~~ storage~~ container **with its container attachments (if applicable)** is pressurized~~ to 180 per cent NWP (+2/-0 MPa) and held at least 4 minutes without burst (~~ **in accordance with the procedure specified in** Annex 3, paragraph 3.1. ~~test procedure).~~

5.2.8. Residual **strength** burst ~~strength ~~test

The~~ storage~~ container **with its container attachments (if applicable)** undergoes a hydraulic burst test**.** ~~to verify that the ~~**The** burst pressure **measured in accordance with the procedure specified in Annex 3, paragraph 2.1. shall be**~~ is~~ at least 80 per cent of the ~~baseline initial burst pressure (~~BP_O~~) determined~~ **provided by the manufacturer** in paragraph 5.1.1. ~~(Annex 3, paragraph 2.1. test procedure).~~

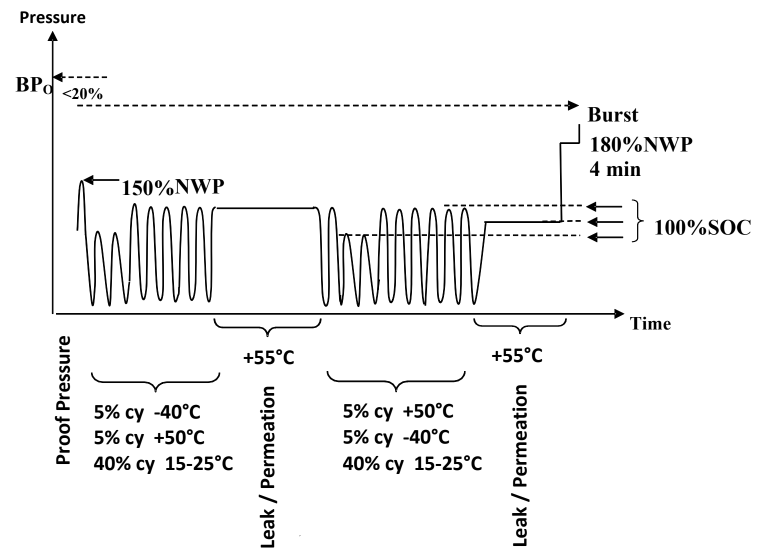
5.3. Verification test for expected on-road performance (Pneumatic sequential tests)

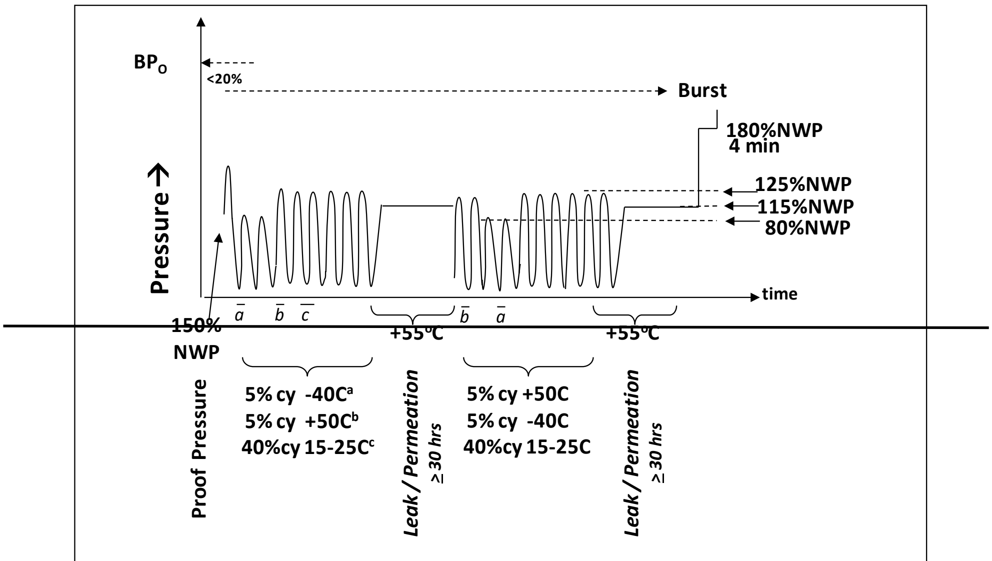
A~~ hydrogen storage system~~**CHSS** shall **undergo** ~~not leak during ~~the following sequence of tests, which are illustrated in Figure **2**~~3~~. Specifics of applicable test procedures for the **CHSS**~~ hydrogen storage system~~ are provided in Annex 3.

The CHSS shall not leak and the primary closure devices shall maintain functionality during the test.

Figure **2~~3~~**

Verification test for expected on-road performance (pneumatic~~/hydraulic~~)





a Fuel/defuel cycles @-40°C with initial system equilibration @ -40°C, 5 cycles with +20°C fuel; 5 cycles with <-35°C fuel
b Fuel/defuel cycles @+50°C with initial system equilibration @+50°C, 5 cycles with <-35°C fuel
c Fuel/defuel cycles @15-25°C with service (maintenance) defuel rate, 50 cycles

5.3.1. Proof pressure test

~~A system~~ **The container of a CHSS** is pressurized **in accordance with the procedure specified in** ~~to 150 per cent NWP (+2/-0 MPa) for at least 30 seconds (~~Annex 3, paragraph 3.1. ~~test procedure).~~ **The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure.** ~~A storage~~ **The** container that has undergone a proof pressure test in manufacture may be exempted from this test.

5.3.2. Ambient and extreme temperature gas pressure cycling test **(pneumatic)**

The ~~system~~ **CHSS** is pressure cycled **in accordance with** ~~using hydrogen gas for 500 cycles (~~Annex 3, paragraph 4.1. ~~test procedure).~~

~~(a) The pressure cycles are divided into two groups: Half of the cycles (250) are performed before exposure to static pressure (paragraph 5.3.3.) and the remaining half of the cycles (250) are performed after the initial exposure to static pressure (paragraph 5.3.3.) as illustrated in Figure 3;~~

~~(b) The first group of pressure cycling, 25 cycles are performed to 80 per cent NWP (+2/-0 MPa) at ≤ -40 °C, then 25 cycles to 125 per cent NWP (+2/-0 MPa) at ≥ +50 °C and 95 (±2) per cent relative humidity, and the remaining 200 cycles to 125 per cent NWP (+2/-0 MPa) at 20 (± 5) °C;~~

~~The second group of pressure cycling, 25 cycles are performed to 125 per cent NWP (+2/-0 MPa) at ≥ +50 °C and 95 (±2) per cent relative humidity, then 25 cycles to 80 per cent NWP (+2/-0 MPa) at ≤ -40 °C, and the remaining 200 cycles to 125 per cent NWP (+2/-0 MPa) at 20 (± 5) °C.~~

~~(c) The hydrogen gas fuel temperature is ≤ -40 °C;~~

~~(d) During the first group of 250 pressure cycles, five cycles are performed with fuel having a temperature of +20 (±5) °C after temperature equilibration of the system at ≤ -40 °C; five cycles are performed with fuel having a temperature of ≤ -40 °C; and five cycles are performed with fuel having a temperature of ≤ -40 °C after temperature equilibration of the system at ≥ +50 °C and 95 per cent relative humidity;~~

~~(e) Fifty pressure cycles are performed using a de-fuelling rate greater than or equal to the maintenance de-fuelling rate.~~

5.3.3. Extreme temperature static **gas** pressure leak/permeation test **(pneumatic)**.

The test shall be conducted in accordance with Annex 3, paragraphs 4.2. and 4.3.

~~(a) The test is performed after each group of 250 pneumatic pressure cycles in paragraph 5.3.2.;~~

~~(b)~~ The maximum allowable hydrogen discharge from the ~~compressed hydrogen storage system~~ **CHSS** is 46 ml/hr/l water capacity of the **CHSS** ~~storage system~~. ~~(Annex 3, paragraph 4.2. test procedure);~~

~~(c) If the measured permeation rate is greater than 0.005 mg/sec (3.6 Nml/min), a localized leak test is performed to ensure no~~ **Any single** point of localized external leakage **measured in accordance with Annex 3, paragraph 4.3. shall not exceed** ~~is greater than~~ 0.005 mg/sec (3.6 Nml/min) ~~(Annex 3, paragraph 4.3. test procedure)~~.

5.3.4. Residual proof pressure test (hydraulic)

The ~~storage~~ container **with its container attachments (if any), as specified,** is pressurized **in accordance with the procedure specified in** ~~to 180 per cent NWP (+2/-0 MPa) and held at least 4 minutes without burst (~~Annex 3, paragraph 3.1. ~~test procedure).~~

5.3.5. Residual strength burst test (hydraulic)

The ~~storage~~ container **with its container attachments (if any), as specified,** undergoes a hydraulic burst**.** ~~to verify that the~~ **The** burst pressure **measured in accordance with the procedure specified in Annex 3, paragraph 2.1. shall be** ~~is~~ at least 80 per cent of the ~~baseline initial burst pressure (~~BP_O~~) determined~~ **provided by the manufacturer** in paragraph 5.1.1. ~~(Annex 3, paragraph 2.1. test procedure).~~

5.4. Verification test for service terminating performance in fire

The CHSS shall undergo the two-stage localized/engulfing fire test specified in Annex 3, paragraph 5.

The CHSS is filled to 100 per cent state-of-charge (SOC) with compressed hydrogen as the test gas.

The CHSS shall vent to less than 1 MPa within 1 hour for vehicles of categories M_1 and N_1 or within 2 hours for vehicles of categories M_2, M_3, N_2 and N_3. If venting occurs from TPRD(s), the venting shall be continuous. The container shall not rupture during the CHSS fire test. Except for discharges from the exhausts of TPRD vents, any leakage, permeation, or venting from the CHSS, including through the container walls or joints, other components, and fittings, shall not result in jet flames greater than 0.5 m.

If the container pressure has not fallen below 1 MPa when the time limit defined above is reached, then fire testing is terminated and the CHSS fails the fire test (even if rupture did not occur).

~~This section describes the fire test with compressed hydrogen as the test gas. Compressed air may be used as an alternative test gas.~~

~~A hydrogen storage system is pressurized to NWP and exposed to fire (Annex 3, paragraph 5.1. test procedure). A temperature-activated pressure relief device shall release the contained gases in a controlled manner without rupture.~~"

Insert new paragraphs 5.5. to 5.5.2.3., to read:

"**5.5. Material compatibility**

The materials used in CHSS shall be compatible with hydrogen when they are in contact with hydrogen in liquid and/or gaseous state. Incompatible materials shall not be in contact with each other.

The manufacturer shall provide the documentation justifying that the materials used in CHSS, except for those of the specific component approved in accordance with Part II of this Regulation, comply with the applicable requirements specified in paragraphs 5.5.1. or 5.5.2. This

requirement does not apply to materials that do not come in contact with hydrogen under normal conditions.

5.5.1. **Metallic materials**

Metallic materials used in CHSS shall be evaluated in accordance with Annex 8 of this Regulation.

5.5.2. **Non-metallic materials**

5.5.2.1 **Plastic liner materials**

The material for plastic liners of hydrogen storage containers may be thermosetting or thermoplastic.

5.5.2.2. **Fibres**

The manufacturer of the container shall keep on file for the intended life of the container design the published specifications for composite materials including principal test results, i.e. tensile test, the material manufacturer's recommendations for storage, conditions and shelf life.

The manufacturer of the container shall keep on file, for the intended life of each batch of containers, the fibre manufacturer's certification that each shipment conforms to the manufacturer's specifications for the product.

The manufacturer shall make the information available immediately upon request of a national authority responsible for market surveillance activities as well as upon request of the type-approval authority.

5.5.2.3. **Resins**

The polymeric material for impregnation of the fibres may be thermosetting or thermoplastic resin."

Renumber (former) paragraphs 5.5.to 5.6. as new paragraphs 5.6. to 5.7., and amend to read:

"5.**6**~~5~~. Requirements for primary closure devices

The primary closure devices that isolate the high pressure hydrogen storage system, namely TPRD, check valve and shut-off valve, ~~as described in Figure 1,~~ shall be tested and type-approved in accordance with Part II of this Regulation and produced in conformity with the approved type**.**

Retesting of the **CHSS** ~~storage system~~ is not required if alternative closure devices are provided having comparable function, fittings, materials, strength and dimensions, and satisfy the condition above. However, a change in TPRD hardware, its position of installation or venting lines shall require a new fire test in accordance with paragraph 5.4.

5.**7**~~6~~. Labelling

A label shall be permanently affixed on each container **or container attachments** with at least the following information: name of the manufacturer, serial number, date of manufacture, MFP, NWP, type of fuel (e.g. "CHG" for gaseous hydrogen), and date of removal from service **as well as**~~. Each container shall also be marked with~~ the number of cycles used in the testing programme as per paragraph 5.1.2. Any label ~~affixed to the container~~ in compliance with this paragraph shall remain in place and be legible for the duration of the manufacturer's recommended service life for the container.

Date of removal from service shall not be more than **25**~~15~~ years ~~(or 20 years)~~ after the date of manufacture. "

Paragraphs 6.1. to 6.2., amend to read:

"6.1. TPRD requirements **[(this includes pressure line for remote TPRDs)]**

TPRDs shall meet the following performance requirements:

(a) Pressure cycling test (Annex 4, paragraph 1.1.);

(**b**~~c~~) Accelerated life test (Annex 4, paragraph 1.2.);

(**c**~~d~~) Temperature cycling test (Annex 4, paragraph 1.3.);

(**d**~~e~~) Salt corrosion resistance test (Annex 4, paragraph 1.4.);

(**e**~~f~~) Vehicle environment test (Annex 4, paragraph 1.5.);

(**f**~~g~~) Stress corrosion cracking test (Annex 4, paragraph 1.6.);

(**g**~~h~~) Drop and vibration test (Annex 4, paragraph 1.7.);

(**h**~~i~~) Leak test (Annex 4, paragraph 1.8.);

(**i**~~j~~) Bench top activation test (Annex 4, paragraph 1.9.);

(**j**~~k~~) Flow rate test (Annex 4, paragraph 1.10.)**;**~~.~~

(k) Atmospheric exposure test (Annex 4, paragraph 1.11.).

6.2. Check valve and~~ automatic~~ shut-off valve requirements

Check valves and~~ automatic~~ shut-off valves shall meet the following performance requirements:

(a) Hydrostatic strength test (Annex 4, paragraph 2.1.);

(b) Leak test (Annex 4, paragraph 2.2.);

(c) Extreme temperature pressure cycling test (Annex 4, paragraph 2.3.);

(d) Salt corrosion resistance test (Annex 4, paragraph 2.4.);

(e) Vehicle environment test (Annex 4, paragraph 2.5.);

(f) Atmospheric exposure test (Annex 4, paragraph 2.6.);

(g) Electrical tests (Annex 4, paragraph 2.7.);

(h) Vibration test (Annex 4, paragraph 2.8.);

(i) Stress corrosion cracking test (Annex 4, paragraph 2.9.);

~~(j) Pre-cooled hydrogen exposure test (Annex 4, paragraph 2.10.).~~ "

Insert new paragraphs 6.3. to 6.3.1., to read:

"6.3. **Material compatibility**

The materials used for TPRD, check valve and shut-off valve shall be compatible with hydrogen when they are in contact with hydrogen in liquid and/or gaseous state and if a failure of a part of the component leads to a leakage. Incompatible materials shall not be in contact with each other.

The manufacturer shall provide the documentation justifying that the materials used in the specific component submitted for approval in

accordance with Part II of this Regulation, comply with the applicable requirements specified in paragraph 6.3.1. This requirement does not apply to materials that do not come in contact with hydrogen under normal conditions.

6.3.1. Metallic materials

Metallic materials used for TPRD, check valve and shut-off valve shall be evaluated in accordance with Annex 8 of this Regulation. [Alternatively, if pressure cycling tests specified in paragraphs 6.1(a) and 6.2(c), are passed according to the requirements using hydrogen gas, then the material compatibility test in Annex 8 Part 1 is deemed to be met for the tested component design.]"

Renumber (former) paragraph 6.3. as new paragraph 6.4.

Paragraph 7., amend to read:

"7. Part III – Specifications of a vehicle fuel system incorporating the compressed hydrogen storage system

This part specifies requirements for the vehicle fuel system, which includes the ~~compressed hydrogen storage system~~ **CHSS**, piping, joints, and components in which hydrogen is present. The **CHSS** ~~hydrogen storage system~~ included in the vehicle fuel system shall be tested and type-approved in accordance with Part I of this Regulation and produced in conformity with the approved type. "

Paragraphs 7.1.1.1. to 7.1.1.2., amend to read:

"7.1.1.1. A compressed hydrogen fuelling receptacle shall prevent reverse flow to the atmosphere. Test procedure is **in accordance with the leak test specified in Annex 4, paragraph 2.2.** ~~by visual inspection.~~

7.1.1.2. ~~Fuelling receptacle label:~~ A label shall be affixed close to the fuelling receptacle; for instance**,** inside a refilling hatch, showing the following information: fuel type (e.g. "CHG" for gaseous hydrogen), MFP, NWP, date of removal from service of containers. "

Insert new paragraph 7.1.1.5., to read:

"**7.1.1.5. The geometry of the fuelling receptacle of compressed hydrogen gas vehicles shall conform to international standard ISO 17268:2020 and be compatible with specification H35, H35HF or H70 depending on its nominal working pressure and specific application.**"

Paragraph 7.1.2., amend to read:

"7.1.2. Over-pressure protection for the ~~low pressure~~ **low-pressure** system (Annex 5, paragraph 6. test procedure)

The hydrogen system downstream of a pressure regulator shall be protected against overpressure due to the possible failure of the pressure regulator. The set pressure of the overpressure protection device shall be lower than or equal to the maximum allowable working pressure for the appropriate section of the hydrogen system. "

Paragraphs 7.1.3.1. to 7.1.3.2., amend to read:

"7.1.3.1. Pressure relief systems (Annex 5, paragraph 6. test procedure)

(a) ~~Storage system TPRDs.~~ The outlet of the vent line, if present, for hydrogen gas discharge from TPRD(s) of the **CHSS** ~~storage system~~ shall be protected **from ingress of dirt and water (e.g.** by a cap**)**;

(b) ~~Storage system TPRDs.~~ The hydrogen gas discharge from TPRD(s) of the **CHSS** ~~storage system~~ shall not be directed **such that the hydrogen exhaust does not impinge upon**:

(i) ~~Into~~ enclosed or semi-enclosed spaces;

(ii) ~~Into or towards~~ any vehicle wheel housing;

(iii) ~~Towards~~ hydrogen gas containers;

(iv) **the vehicle's REESS**.~~Forward from the vehicle, or horizontally (parallel to road) from the back or sides of the vehicle;~~

~~(c) Other pressure relief devices (such as a burst disc) may be used outside the hydrogen storage system. The hydrogen gas discharge from other pressure relief devices shall not be directed~~

~~(i) Towards exposed electrical terminals, exposed electrical switches or other ignition sources;~~

~~(ii) Into or towards the vehicle passenger or luggage compartments;~~

~~(iii) Into or towards any vehicle wheel housing;~~

~~(iv) Towards hydrogen gas containers;~~

7.1.3.2. Vehicle exhaust system (Annex 5, paragraph 4. test procedure)

At the vehicle exhaust system's point of discharge, the hydrogen concentration level shall:

(a) Not exceed 4**.0** per cent average by volume during any moving three-second time interval during normal operation including start-up and shut-down;

(b) And not exceed 8**.0** per cent at any time (Annex 5, paragraph 4. test procedure). "

Paragraph 7.1.4.1., amend to read:

"7.1.4.1. Hydrogen **gas discharge,** leakage and/or permeation from the **vehicle fuel** ~~hydrogen storage~~ system shall not directly vent into the passenger or luggage compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contains unprotected ignition sources. "

Paragraph 7.1.5., amend to read:

"7.1.5. Fuel system leakage

The hydrogen fuelling line ~~(e.g. piping, joint, etc.)~~ downstream of the main shut-off valve(s) to the fuel cell system or the engine shall not leak. Compliance shall be verified at NWP (Annex 5, paragraph 5. test procedure)."

Paragraph 7.2., amend to read:

"7.2. Post-crash fuel system integrity

The vehicle fuel system shall comply with the following requirements after the vehicle crash tests in accordance with the following UN Regulations by also applying the test procedures prescribed in Annex 5 to this Regulation.

(a) Frontal impact test **procedures** in accordance with ~~either Regulation No. 12, or~~ Regulation No. 94**, Annex 3 and Regulation No. 137, Annex 3 only to the extent where the Regulations apply as prescribed in their scope**; and

(b) Lateral impact test **procedures** in accordance with UN Regulation No. 95**, Annex 4**.

At the request of the manufacturer, for vehicles not in the scope of these UN Regulations [and that are derived from M_1 or N_1 vehicle categories], they may be tested in accordance with the crash test procedures in these UN Regulations.]

[This requirement is deemed to be met if the vehicle equipped with CHSS is approved in accordance with UN Regulation No. 94 (05 series of amendments or later) or UN Regulation No. 137 (03 series of amendments or later) for frontal impact and UN Regulation No. 95 (06 series of amendments or later) for lateral impact, as applicable in the scope of aforementioned crash regulations.]

In case that one or ~~both~~ **more directions** of the vehicle crash tests specified above are not applicable to the vehicle, the ~~compressed hydrogen storage system~~ **CHSS** shall, instead, be subject to the relevant alternative accelerations **in compliance with the acceleration corridors which are specified in Tables 3 to 5 in both positive and negative directions.** ~~specified below and the compressed hydrogen storage system~~ **CHSS** shall comply with the relevant requirements in paragraphs 7.2.3. and 7.2.4. The accelerations shall be measured at the location where the ~~compressed hydrogen storage system~~ **CHSS** is installed. The ~~compressed hydrogen storage system~~ **CHSS** shall be mounted and fixed on the representative part of the vehicle. The mass used shall be representative for a fully equipped and filled **CHSS**~~container or container assembly~~.

~~Accelerations for vehicles of categories M_1 and N_1:~~

~~(a) 20 g in the direction of travel (forward and rearward direction);~~

~~(b) 8 g horizontally perpendicular to the direction of travel (to left and right).~~

~~Accelerations for vehicles of categories M_2 and N_2:~~

~~(a) 10 g in the direction of travel (forward and rearward direction);~~

~~(b) 5 g horizontally perpendicular to the direction of travel (to left and right).~~

~~Accelerations for vehicles of categories M_3 and N_3:~~

~~(a) 6.6 g in the direction of travel (forward and rearward direction);~~

~~(b) 5 g horizontally perpendicular to the direction of travel (to left and right).~~

The test pulse shall be within the minimum and maximum value as specified in Tables 3 to 5. A higher shock level and /or longer duration as

described in the maximum value in Tables 3 to 5 can be applied to the CHSS if recommended by the manufacturer.

Figure 3
Generic description of test pulses

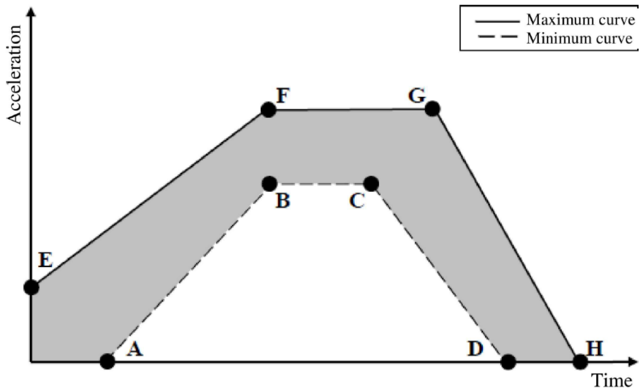


Table 3
for M_1 and N_1 vehicles:

Point	*Time (ms)*	*Acceleration (g)*	
		Longitudinal	*Transverse*
A	20	0	0
B	50	20	8
C	65	20	8
D	100	0	0
E	0	10	4.5
F	50	28	15
G	80	28	15
H	120	0	0

Table 4
for M_2 and N_2 vehicles:

Point	*Time (ms)*	*Acceleration (g)*	
		Longitudinal	*Transverse*
A	20	0	0
B	50	10	5
C	65	10	5
D	100	0	0
E	0	5	2.5

F	**50**	**17**	**10**
G	**80**	**17**	**10**
H	**120**	**0**	**0**

Table 5
for M_3 and N_3 vehicles:

Point	***Time (ms)***	***Acceleration (g)***	
		Longitudinal	***Transverse***
A	**20**	**0**	**0**
B	**50**	**6,6**	**5**
C	**65**	**6,6**	**5**
D	**100**	**0**	**0**
E	**0**	**4**	**2.5**
F	**50**	**12**	**10**
G	**80**	**12**	**10**
H	**120**	**0**	**0**

A calculation method may be used instead of practical acceleration testing if its equivalence can be demonstrated by the manufacturer to the satisfaction of the Technical Service and in agreement with the Type Approval Authority."

Paragraph 7.2.3., amend to read:

"7.2.3. Container Displacement

The ~~storage~~ container(s) shall remain attached to the vehicle at a minimum of one attachment point."

Paragraphs 7.2.4.1. to 7.2.4.2., amend to read:

"7.2.4.1. Requirements on installation of the hydrogen storage system not subject to the frontal impact test:

The **CHSS** ~~container~~ shall be mounted **so that its primary closure devices are located** in a position which is rearward of a vertical plane perpendicular to the centre line of the vehicle and located 420 mm rearward from the front edge of the vehicle. **In any case the container should never be the outermost part of the vehicle.**

7.2.4.2. Requirements on installation of the hydrogen storage system not subject to the lateral impact test:

The **CHSS** ~~container~~ shall be mounted **so that its primary closure devices are located** in a position which is between the two vertical planes parallel to the centre line of the vehicle located 200 mm inside from the both outermost edge of the vehicle in the proximity of its container(s). **In any case the container should never be the outermost part of the vehicle.** "

[*Paragraph 7.2.4.3.,* amend to read:

"7.2.4.3. Lateral impact test on compressed hydrogen storage system as alternative to 7.2.4.2.

Upon the manufacturer's request, for compressed hydrogen storage systems installed in vehicles to which the vehicle crash test specified in 7.2. (b) is not **applied** ~~applicable~~, the additional installation requirement under 7.2.4.2. does not apply if the compressed hydrogen storage system **is installed at a height equal to or less than 800 mm from the ground and** has passed the lateral impact test specified below:"]

Paragraph 7.2.4.3.3., amend to read:

["7.2.4.3.3. Lateral impact on compressed hydrogen storage system

The MDB speed at the moment of impact shall be 50 ± 1 km/h. However, if the test was performed at a higher impact speed and the compressed hydrogen storage system met the requirements, the test shall be considered satisfactory. The impact direction shall be in an angle of 90° to the longitudinal axis of the test set-up as defined in paragraph 7.2.4.3.1. and the **CHSS** container shall be adjusted in a way that the middle of the front plate of the barrier matches the middle of the **primary closure location** ~~container~~ in the horizontal and vertical. **In case more than one primary closure locations, the worst-case impact area shall be selected for the test in agreement with the Technical Service.**

After this lateral impact test the compressed hydrogen storage system shall comply with the requirements in 7.2.1. and 7.2.3.]"

[*Paragraphs 9. to* 9.3.2.3.7.*,* amend to read:

"9. Conformity of production

9.1. Procedures concerning conformity of production shall conform to the general provisions defined in ~~Appendix 2~~ **Schedule 1** to the Agreement (E/ECE/324-E/ECE/TRANS/505/Rev.**3**~~2~~)~~. and at least meet the following requirements:~~

[9.2. The production control of the compressed hydrogen storage system container shall satisfy the following additional requirements;

9.2.1. Every container or every pressure bearing chamber of CHSS shall be pressurized smoothly and continually with a hydraulic fluid or gas to the target pressure of ≥ 125 per cent NWP until the target test pressure level is reached and then held for ≥ 30 seconds. Temperature variation during the test shall be taken into account.

9.2.2. Sampling test

9.2.2.1. The sampling test and production control shall be implemented based on the batch of products. The maximum size of the batch shall not exceed 200 units or one shift of successive production, whichever is greater. The manufacturer shall conduct the tests specified in paragraph 9.2.3. on at least one CHSS randomly sampled from each batch of CHSS produced. In case that any defects are confirmed through the sampling tests, the manufacturer shall prevent the use of all CHSS in the same batch.

9.2.2.2. **On 10 sequential production batches of the same design, should none of the pressure cycled cylinders leak or rupture in less than 11,000 cycles x 2.0, then the pressure cycling test can be reduced to one cylinder from every 10 batches of production.**

9.2.2.3. **The manufacturer [condition TBD] may, at its own discretion, apply alternative procedure for sampling CHSS from its production together with appropriate measures to trace the quality control data, that are sufficient to monitor the production variances due to different factors e.g., material, process, environments, for each CHSS produced. The manufacturer shall conduct the tests specified in paragraph 9.2.3. on CHSS randomly sampled according to the sampling rate determined by the manufacturer. In case that any defects are confirmed through the sampling tests, the manufacturer shall identify all the CHSS potentially having the same defects and take the appropriate measures to prevent further use of such CHSS.**

The sampling rate determined by the manufacturer shall be based on logical justifications and verified as a part of initial assessment in accordance with paragraph 9.1. Such sampling rate may include a strategy to adapt the sampling rate according to the factors influencing the stability of the product quality.

9.2.3. **Procedure for sampling tests**

9.2.3.1. **Burst test**

The test shall be performed according to Annex 3, paragraph 2.1. (burst test). The rupture pressure of each sample tested shall be at least BPmin and the average burst pressure recorded of the last ten tests shall be at or above BPo -10 per cent.

9.2.3.2. **Ambient temperature pressure cycling test in batch testing**

The test shall be performed according to paragraph 2.2. (a) to (c) (hydrostatic pressure cycling test) of Annex 3, except that the temperature requirements for the fuelling fluid and the container skin, and the relative humidity requirement, do not apply. The container of the CHSS shall be pressure cycled using hydrostatic pressures ≥ 125 per cent of NWP, to 22,000 cycles in case of no leakage or until leakage occurs. The container of the CHSS shall not leak or rupture within the first 11,000 cycles.]

~~9.1.~~ ~~A vehicle, hydrogen storage system or component approved pursuant to this Regulation shall be so manufactured as to conform to the type approved by meeting the respective requirements of paragraphs 5. to 7. above;~~

~~9.2.~~ ~~The Type Approval Authority which has granted approval may at any time verify the conformity of control methods applicable to each production unit. The normal frequency of such inspections shall be once every two years.~~

9.3. ~~In case of compressed hydrogen storage system, the~~ production control of the container shall satisfy the following additional requirements;

~~9.3.1.~~ ~~Every container shall be tested in accordance with paragraph 5.2.1. of this Regulation. The test pressure is ≥ 150 per cent of NWP.~~

~~9.3.2.~~ ~~Batch testing~~

In any case, for each batch, which is not permitted to exceed 200 finished cylinders or liners (not including destructive test cylinders or liners), or one shift of successive production, whichever is greater, at least one container shall be subjected to the rupture test in paragraph 9.3.2.1. and furthermore at least one container shall be subjected to the pressure cycle test in paragraph 9.3.2.2.

9.3.2.1. Rupture test in batch testing

The test shall be performed according to paragraph 2.1. (hydrostatic pressure rupture **burst** test) of Annex 3. The required rupture **burst** pressure shall be at least BPmin and the average burst pressure recorded of the last ten tests shall be at or above BP_O -10 per cent.

9.3.2.2. Ambient temperature pressure cycling test in batch testing

The test shall be performed according to paragraph 2.2. (a) to (c) (hydrostatic pressure cycling test) of Annex 3, except that the temperature requirements for the fuelling fluid and the container skin, and the relative humidity requirement, do not apply. The cylinder shall be pressure cycled using hydrostatic pressures ≥ 125 per cent of NWP, to 22,000 cycles in case of no leakage or until leakage occurs. For the service life of 15 years, t**T**he cylinder shall not leak or rupture within the first 11,000 cycles, or for the service life of 20 years, within the first 15,000 cycles.

9.3.2.3. Relaxation provisions

In the ambient temperature pressure cycling test in batch testing, finished cylinders shall be pressure cycled at a sampling frequency defined as follows:

9.3.2.3.1. One cylinder from each batch shall be pressure cycled with 11,000 cycles for the service life of 15 years or with 15,000 cycles for the service life of 20 years depending on the intended use of the container.

9.3.2.3.2. On 10 sequential production batches of the same design, should none of the pressure cycled cylinders leak or rupture in less than 11,000 cycles x 1.5 for the service life of 15 years or in less than 15,000 cycles x 1.5 for the service life of 20 years, then the pressure cycling test can be reduced to one cylinder from every 5 batches of production.

9.3.2.3.3. On 10 sequential production batches of the same design, should none of the pressure cycled cylinders leak or rupture in less than 11,000 cycles x 2.0 for the service life of 15 years or in less than 15,000 cycles x 2.0 for the service life of 20 years, then the pressure cycling test can be reduced to one cylinder from every 10 batches of production.

9.3.2.3.4. Should more than 6 months have expired since the last batch of production, then the sampling frequency for the next batch of production shall be that specified in paragraph 9.3.2.3.2. or 9.3.2.3.3. above.

9.3.2.3.5. Should any cylinder tested at the sampling frequency in paragraph 9.3.2.3.2. or 9.3.2.3.3. above fail to meet the required number of pressure cycles, then it shall be necessary to repeat the pressure cycling test at the sampling frequency in paragraph 9.3.2.3.1 above for a minimum 10 production batches. The sampling frequency for testing thereafter shall be that specified in paragraph 9.3.2.3.2. or 9.3.2.3.3. above.

9.3.2.3.6. Should any cylinder tested at the sampling frequency in paragraph 9.3.2.3.1., 9.3.2.3.2. or 9.3.2.3.3. above fail to meet the minimum requirement regarding

~~the number of pressure cycles (11,000 cycles), then the cause of failure shall be determined and corrected following the procedures in paragraph 9.3.2.3.7.~~

~~The pressure cycling test shall then be repeated on an additional three cylinders from that batch. Should any of the three additional cylinders fail to meet the minimum requirement regarding the number of pressure cycles (11,000 cycles), then all cylinders of this batch shall be rejected.~~

~~9.3.2.3.7. In the event of failure to meet test requirements retesting or reheat treatment and retesting shall be carried out as follows:~~

~~(a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored;~~

~~(b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.~~

~~All **containers** cylinders that fail to meet the requirements shall be rejected or repaired by an approved method. The non-rejected **containers** cylinders are then considered as a new batch.~~

~~In any case, the new batch shall be retested. All the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If any **container** cylinder in a batch is proven unsatisfactory by one or more tests, all **containers** cylinders of this batch shall be rejected.~~] "

Paragraph 13.1., amend to read:

"13.1. As from the official date of entry into force of the **02**~~01~~ series of amendments, no Contracting Party applying this UN Regulation shall refuse to grant or refuse to accept UN type approvals under this UN Regulation as amended by the **02**~~01~~ series of amendments. "

Paragraph 13.6., amend to read:

"13.6. **As from 1 September [2027], Contracting Parties applying this Regulation shall not be obliged to accept type approvals to the preceding series of amendments, first issued after 1 September [2027].**~~Contracting Parties applying this Regulation shall not refuse to grant type approvals according to any preceding series of amendments to this Regulation or extension thereof.~~ "

Insert new paragraphs 13.7. to 13.9., to read:

"13.7. Contracting Parties applying this Regulation shall continue to accept type approvals issued according to any of the preceding series of amendments to this Regulation first issued before 1 September [2027], provided the transitional provisions in these respective previous series of amendments foresee this possibility.

13.8. Contracting Parties applying this Regulation may grant type approvals according to any preceding series of amendments to this Regulation.

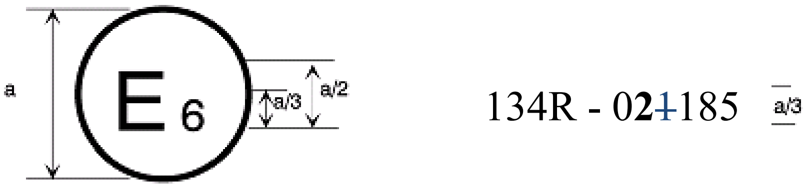
13.9. Contracting Parties applying this Regulation shall continue to grant extensions of existing approvals to any preceding series of amendments to this Regulation. "

Annex 2., amend to read:

"Annex 2

Arrangements of the approval marks

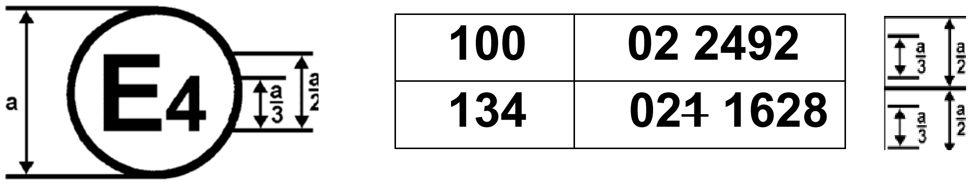
Model A
(See paragraphs 4.4. to 4.4.2. of this Regulation)



a = 8 mm min

The above approval mark affixed to a vehicle/ storage system/specific component shows that the vehicle/storage system/specific component type concerned has been approved in Belgium (E 6) for its the safety-related performance of hydrogen-fuelled vehicles pursuant to Regulation No. 134. The first two digits of the approval number indicate that the approval already contained the **02** ~~01~~ series of amendments at the time of approval.

Model B
(See paragraph 4.5. of this Regulation)



a = 8 mm min.

The above approval mark affixed to a vehicle shows that the road vehicle concerned has been approved in the Netherlands (E 4) pursuant to Regulations Nos. 134 and 100.* The approval number indicates that, at the dates when the respective approvals were granted, Regulation No. 100 was amended by the 02 series of amendments and Regulation No. 134 was amended by the **02**~~01~~ series of amendments. "

* The latter number is given only as an example.

Annex 3 (all paragraphs)., amend to read:

"Annex 3

Test procedures for the compressed hydrogen storage system

1. Test procedures for qualification requirements of **CHSS** compressed hydrogen storage are organized as follows:

Paragraph 2 of this annex is **Paragraphs 2. and 3. of this Annex contains** the test procedures for baseline performance metrics (requirement of paragraph 5.1. of this Regulation) **and performance durability (requirement of paragraph 5.2. of this Regulation)**

Paragraph 3 of this annex is the test procedures for performance durability (requirement of paragraph 5.2. of this Regulation)

Paragraph 4 of this annex **Annex contains** is the test procedures for expected on-road performance (requirement of paragraph 5.3. of this Regulation)

Paragraph 5 of this annex **Annex contains** is the test procedures for service terminating performance in fire (requirement of paragraph 5.4. of this Regulation)

Paragraph 6 of this annex **Annex** is the test procedures for performance durability of primary closures (requirement of paragraph 5.5. of this Regulation)

Unless otherwise specified, the ambient temperature for all tests shall be 20 ± 15°C.

Unless otherwise specified data sampling for pressure cycling shall be at least 1 Hz.

Unless otherwise specified, the acceptable tolerances of the open ended test parameters may be recommended by the manufacturer.

2. Test procedures for baseline performance metrics (requirement of paragraph 5.1. of this Regulation)

2.1. Burst test (hydraulic)

The burst test is conducted at the ambient temperature of 20 (±5) °C using a **hydraulic** non-corrosive fluid. The rate of pressurization is less than or equal to 1.4 MPa/sec for pressures higher than 150 per cent of the nominal working pressure. If the rate exceeds 0.35 MPa/sec at pressures higher than 150 per cent NWP, then either the container is placed in series between the pressure source and the pressure measurement device, or the time at the pressure above a target burst pressure exceeds 5 seconds. The burst pressure of the container shall be recorded.

2.2. **Ambient** P**p**ressure cycling test (hydraulic)

The test is performed in accordance with the following procedure **and the test parameters specified in Table 1 below**:

(a) The container **test article** is filled with a **hydraulic** non-corrosive fluid;

(b) The ~~container~~ **test article** and fluid are stabilized at **the temperature specified in Table 1** ~~the specified temperature and relative humidity~~ at the start of testing**.** ~~; t~~**T**he environment, ~~fuelling~~ **hydraulic** fluid and **the surface of the test article** ~~container skin~~ are maintained at the specified temperature for the duration of the **cycling** ~~testing~~. The ~~container~~ **test article** temperature may vary from the environmental temperature during **cycling** ~~testing~~;

(c) The ~~container~~ **test article** is pressure cycled between 2 ~~(±1)~~ MPa and the target pressure**s specified in accordance with Table 1**~~at a rate not exceeding 10 cycles per minute for the specified number of cycles~~;

(d) The temperature of the hydraulic fluid ~~within~~ **entering** the container ~~is~~ **shall be** maintained ~~and monitored~~ at the specified temperature **and monitored as close as possible to the container inlet;**~~.~~

Note: The manufacturer may specify a hydraulic pressure cycle profile that will prevent premature failure of the container due to test conditions outside of the container design envelope.

Table 1
Pressure cycles and conditions

Purpose	*Number of cycles*	*Target Pressure*	*Temperature*	*Rate*
Baseline initial pressure cycling life (paragraph 5.1.2.)	**22,000 or until leak occurs**	**≥ 125 per cent NWP**	**Environment: 20 ± 15 °C** **Hydraulic fluid: 20 ± 15 °C**	**≤ 10 cycles per minute**

3. Test procedures for performance durability (requirement of paragraph 5.2. of this Regulation)

3.1. Proof pressure test

The ~~system~~ **container with its container attachments (if any), as specified,** is pressurized smoothly and continually with a ~~non-corrosive~~ hydraulic fluid **or gas** until the target test pressure level is reached and then held for the **duration specified in Table 2 below:** ~~specified time.~~

Table 2
Target pressure and holding duration of proof pressure test

Purpose	*Target pressure*	*Holding duration*
(initial) proof pressure test (paragraphs 5.2.1. and 5.3.1.)	**≥ 150 per cent NWP**	**≥ 30 second**
Residual proof pressure test (paragraphs 5.2.7. and 5.3.4.)	**≥ 180 per cent NWP**	**≥ 4 minutes**

3.2. Drop (impact) test (unpressurized)

The~~ storage~~ container **and its container attachments (if any)** is drop tested~~ at ambient temperature~~ without internal pressurization or attached valves. The surface onto which the~~ containers are~~ **test article is** dropped shall be a smooth, horizontal concrete pad or other flooring type with equivalent hardness. **No attempt shall be made to prevent the test article from bouncing or falling over during a drop test, but the test article shall be prevented from falling over during the vertical drop test.**

The **test article**~~ orientation of the container being dropped (in accordance with the requirement of paragraph 5.2.2.) is determined as follows: One or more additional container(s)~~ shall be dropped in **any one of the following four orientations:** ~~each of the orientations described below. The drop orientations may be executed with a single container or as many as four containers may be used to accomplish the four drop orientations.~~

(i) ~~Dropped once f~~**F**rom a horizontal position with the bottom 1.8 m above the surface onto which it is dropped**. In case of non-axisymmetric container, the largest projection area of the container shall be oriented downward and aligned horizontally, the shut-off valve interface location and its centre of gravity should be horizontally aligned as it is feasible**;

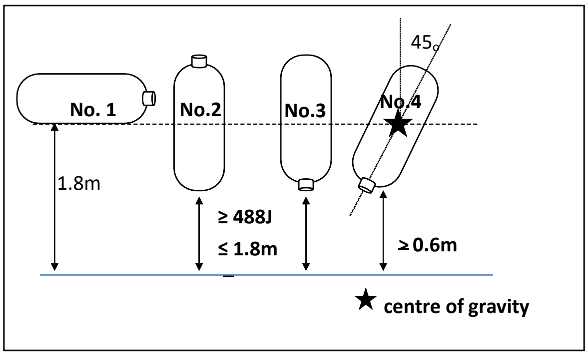
(ii) ~~Dropped once onto the end of the container f~~**F**rom a vertical position with the **shut-off valve interface location**~~ ported end~~ upward**,** with a **drop height calculated based on** a potential energy of~~ not less than~~ 488 J**.**~~, with the height of the lower end no greater than ≤1.8 m~~**. In no case shall the height of the lower end be less than 0.1m or greater than 1.8m. In case of non-axisymmetric container, the shut-off valve interface location and its centre of gravity shall be vertically aligned**;

(iii) ~~Dropped once onto the end of the container f~~**F**rom a vertical position with the **shut-off valve interface location**~~ ported end~~ downward**,** with a **drop height calculated based on** a potential energy of ~~not less than~~ 488 J.**, In no case shall the height of the lower end be less than 0.1m or greater than 1.8m**. If the container is symmetrical (identical~~ ported~~ ends), this drop orientation is not required**. In case of non-axisymmetric container, the shut-off valve interface location and its centre of gravity shall be vertically aligned**;

(iv) ~~Dropped once at~~ **From** a 45° angle from the vertical orientation with **the shut-off valve interface location**~~ a ported end~~ downward with its centre of gravity ≤ 1.8 m above the ground. However, if the bottom is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a centre of gravity of ≤ 1.8 m above the ground. **In case of non-axisymmetric container, the line passing the shut-off valve interface location end and its centre of gravity shall be 45° angled from vertical orientation and the shut-off valve interface location shall become the lowest.**

The four drop orientations are illustrated in Figure 1.

Figure 1
Drop orientations



~~No attempt shall be made to prevent the bouncing of containers, but the containers may be prevented from falling over during the vertical drop tests described above.~~

~~If more than one container is used to execute all drop specifications, then those containers shall undergo pressure cycling according to Annex 3, paragraph 2.2. until either leakage or 22,000 cycles for a 15-year service life or 30,000 cycles for a 20-year service life without leakage have occurred. Leakage shall not occur within 11,000 cycles for a 15-year service life or 15,000 cycles for a 20-year service life.~~

~~The orientation of the container being dropped in accordance with the requirement of paragraph 5.2.2. shall be identified as follows:~~

~~(a) If a single container was subjected to all four drop orientations, then the container being dropped in accordance with the requirement of paragraph 5.2.2. shall be dropped in all four orientations;~~

~~(b) If more than one container is used to execute the four drop orientations, and if all containers reach 22,000 cycles for a 15-year service life or 30,000 cycles for a 20-year service life without leakage, then the orientation of the container being dropped in accordance with the requirement paragraph 5.2.2. is the 45° orientation (iv), and that container shall then undergo further testing as specified in paragraph 5.2.;~~

~~(c) If more than one container is used to execute the four drop orientations and if any container does not reach 22,000 cycles for a 15-year service life or 30,000 cycles for a 20-year service life without leakage, then the new container shall be subjected to the drop orientation(s) that resulted in the lowest number of cycles to leakage and then will undergo further testing as specified in paragraph 5.2.~~

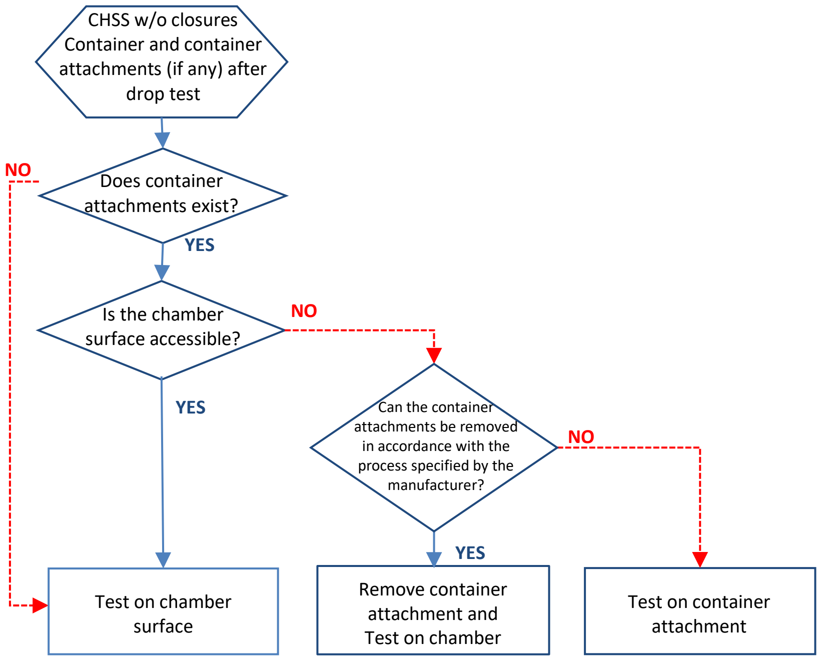
3.3. Surface damage test (unpressurized)

The surface damage tests and the chemical exposure tests (Annex 3, paragraph 3.4.) shall be conducted on the surface of the pressure bearing chamber of the container as long as it is accessible regardless of the existence of the container attachments.

If the container attachments can be removed in accordance with the process specified by the manufacturer, then the container attachments shall be removed, and the tests shall be conducted on the surface of the pressure bearing chamber of the container.

Otherwise, the tests shall be conducted on the surface of the container attachments as indicated in Figure 2.

Figure 2
Surface damage flow chart



The test proceeds in the following sequence:

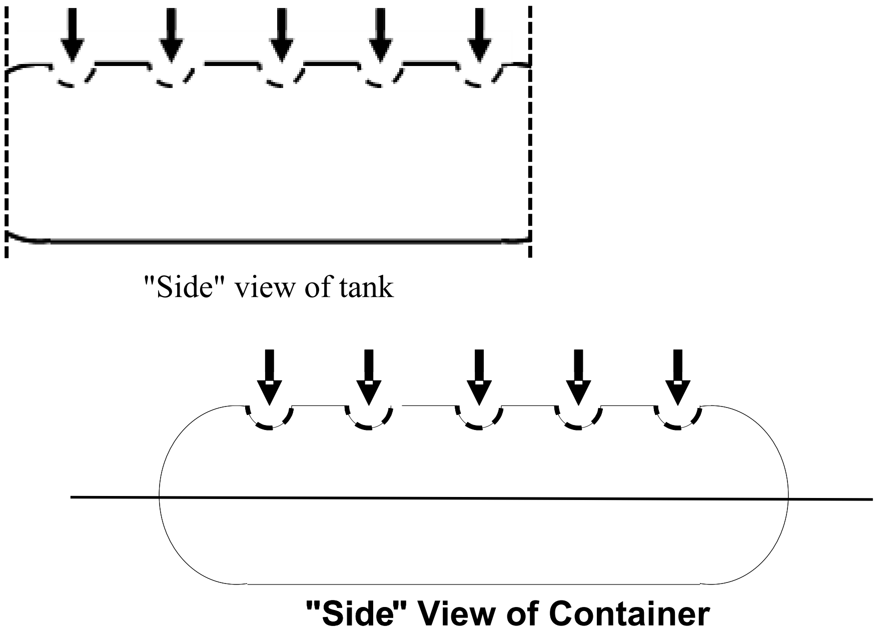
(a) Surface flaw generation: **A saw cut at least 0.75mm deep and 200mm long is made on the surface specified above.**

If the container is to be affixed to the vehicle by compressing its composite surface, then a second cut at least 1.25 mm deep and 25 mm long is applied at the end of the container which is opposite to the location of the first cut; ~~Two longitudinal saw cuts are made on the bottom outer surface of the unpressurized horizontal storage container along the cylindrical zone close to but not in the shoulder area. The first cut is at least 1.25 mm deep and 25 mm long toward the valve end of the container. The second cut is at least 0.75 mm deep and 200 mm long toward the end of the container opposite the valve;~~

(b) Pendulum impacts: **A surface of the test article opposite to the surface specified above or a surface of a different chamber, in the**

case of a container with multiple permanently interconnected chambers, ~~The upper section of the horizontal storage container~~ is divided into five distinct (not overlapping) areas 100 mm in diameter each (see Figure **3**~~2~~). ~~After~~ **Immediately following a minimum of** 12 hours preconditioning at ≤ **-**40 °C in an environmental chamber, the centre of each of the five areas sustains the impact of a pendulum having a pyramid with equilateral faces and square base, the summit and edges being rounded to a radius of 3 mm. The centre of impact of the pendulum coincides with the centre of gravity of the pyramid. The energy of the pendulum at the moment of impact with each of the five marked areas on the container is ≥ 30 J. The ~~container~~ **test article** is secured in place during pendulum impacts and not under pressure.

Figure **3**~~2~~
Side view of container



3.4. Chemical exposure and ambient-temperature pressure cycling test

Each of the 5 areas of the unpressurized container **(with container attachments, if applicable)** preconditioned by pendulum impact (Annex 3, paragraph 3.3.) is exposed to one of five solutions:

(a) 19 per cent (by volume) sulphuric acid in water (battery acid);

(b) 25 per cent (by weight) sodium hydroxide in water;

(c) 5 per cent (by volume) methanol in gasoline (fluids in fuelling stations);

(d) 28 per cent (by weight) ammonium nitrate in water (urea solution); and

(e) 50 per cent (by volume) methyl alcohol in water (windshield washer fluid).

The test **article**~~ container~~ is oriented with the fluid exposure areas on top. A pad of glass wool approximately 0.5 mm thick and 100 mm in diameter is placed on each of the five preconditioned areas. A sufficient amount of the test fluid is applied to the glass wool sufficient to ensure that the pad is wetted across its surface and through its thickness for the duration of the test. **A plastic covering may be applied over the glass wool to prevent evaporation.**

The exposure of the **test article**~~ container~~ with the glass wool is maintained for **at least** 48 hours with the **test article**~~ container~~ held at ≥ 125 per cent NWP ~~(+2/-0 MPa)~~ (applied hydraulically) and **ambient temperature**~~ 20 (±5) °C~~ before the **test article**~~ container~~ is subjected to further testing.

~~Pressure cycling is performed the specified target pressures according to paragraph 2.2. of this Annex 20 (±5) °C for the specified numbers.~~ **The test article is pressure cycled from 2 ± 1 MPa to the target pressures specified in Table 3.** The glass wool pads are removed and the container surface is rinsed with water **after** the~~ final 10 cycles to specified final target~~ pressure **cycling is completed**~~are conducted~~.

Table 3
Pressure cycles and conditions - chemical exposure and ambient temperature pressure cycling test

Purpose	*Number of cycles*	*Target Pressure*	*Temperature*	*Rate*
Chemical exposure and ambient temperature pressure cycling test **(para. 5.2.4.)**	**60 per cent the specified number of cycles determined in paragraph 5.1.2.**	**≥ 125 per cent NWP**	**Environment: 20 ± 15 °C** **Hydraulic fluid: 20 ± 15 °C**	**≤ 10 cycles per minute**
	of which the last 10 cycles	**≥ 150 per cent NWP**		

3.5. Static pressure test (hydraulic)

The **test article**~~ storage system~~ is **filled with a hydraulic fluid and** pressurized to **≥ 125 per cent NWP**~~ the target pressure~~ in a temperature-controlled chamber **at ≥ 85 °C for at least 1,000 hr during which the**~~. The~~ temperature of the chamber and the **surface of the test article are maintained** ~~non-corrosive fuelling fluid is held~~ at the target temperature~~ within ±5 °C~~ for the specified duration.

3.6. Extreme temperature pressure cycling test

The test is performed in accordance with the following procedure and the test parameters specified in Table 4:

(a) The test article is filled with a hydraulic fluid for each test;

(b) The test article and fluid are stabilized at the temperature and relative humidity specified in Table 4 at the start of each test. The environment, hydraulic fluid and the surface of the test article are maintained at the specified temperature for the duration of the cycling. The test article temperature may vary from the environmental temperature during cycling;

(c) The test article is pressure cycled from 2 ± 1 MPa to the target pressures specified in Table 4;

(d) The temperature of the hydraulic fluid entering the container shall be maintained at the specified temperature and monitored as close as possible to the container inlet.

Note: It is recommended that the container is kept at greater than atmospheric pressure for the duration of the testing and is only depressurized once stabilized to ambient temperature.

Table 4
Pressure cycles and conditions - extreme temperature pressure cycling test

Purpose	*Number of cycles*	*Target Pressure*	*Temperature*	*Rate*
Extreme cold test	**20 per cent the specified number of cycles determined in paragraph 5.1.2.**	**≥ 80 per cent NWP**	**Environment: ≤ -40 °C at the start of each test** **Hydraulic fluid and surface: ≤ -40 °C for duration of the cycling**	**≤ 10 cycles per minute**
Extreme hot test	**20 per cent the specified number of cycles determined in paragraph 5.1.2.**	**≥ 125 per cent NWP**	**Environment: ≥ 85 °C and ≥ 80 per cent relative humidity** **Hydraulic fluid & surface: ≥ 85 °C for duration of the cycling**	**≤ 10 cycles per minute**

4. Test procedures for expected on-road performance (paragraph 5.3. of this Regulation)

~~(Pneumatic test procedures are provided; hydraulic test elements are described in Annex 3, paragraph 2.1.)~~

Test sequence and parameters of the ambient and extreme temperature gas pressure cycling test are specified in Tables 5a and 5b.

Table 5a
Ambient and extreme temperature gas pressure cycling test parameters

No. of cycles	***Ambient Conditions***	***Initial System Equilibration***	***Fuel Delivery Temperature***	***Initial Pressure***	***Target Pressure***
5	**≤ -25°C**	**≤ -25°C**	**20 ± 5°C**	**≤ 2 MPa**	**≥ 100 % SOC**
5	**≤ -25°C**	**≤ -25°C**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
15	**≤ -25°C**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
5	**≥ 50°C, ≥ 80 % relative humidity**	**≥ 50°C, ≥ 80 % relative humidity**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
20	**≥ 50°C, ≥ 80 % relative humidity**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
200	**20°C ± 5°C**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
1st permeation	**55°C to 60°C**	**55°C to 60°C**	**N/A**	**N/A**	**≥ 100 % SOC**
25	**≥ 50°C, ≥ 80 % relative humidity**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
25	**≤ -25°C**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
200	**20 ± 5°C**	**N/A**	**-33°C to -40°C**	**≤ 2 MPa**	**≥ 100 % SOC**
2nd permeation	**55°C to 60°C**	**55°C to 60°C**	**N/A**	**N/A**	**≥ 100 % SOC**

Table 5b
CHSS pressurization rates for ambient and extreme temperature gas pressure cycling tests

CHSS VOLUME (L)	***CHSS Pressurization Rate (MPa/min)***			
	50 °C Ambient -40 °C ≤ T_{fuel} ≤ -33 °C	***20 °C Ambient -40 °C ≤ T_{fuel} ≤ -33 °C***	***-25 °C Ambient -40 °C ≤ T_{fuel} ≤ -33 °C***	***-25 °C Ambient T_{fuel} = 20 °C +/- 5 °C***
50	**7.6**	**19.9**	**28.5**	**13.1**
100	**7.6**	**19.9**	**28.5**	**7.7**
174	**7.6**	**19.9**	**19.9**	**5.2**
250	**7.6**	**19.9**	**19.9**	**4.1**
300	**7.6**	**16.5**	**16.5**	**3.6**
400	**7.6**	**12.4**	**12.4**	**2.9**
500	**7.6**	**9.9**	**9.9**	**2.3**
600	**7.6**	**8.3**	**8.3**	**2.1**
700	**7.1**	**7.1**	**7.1**	**1.9**
1000	**5.0**	**5.0**	**5.0**	**1.4**
1500	**3.3**	**3.3**	**3.3**	**1.0**
2000	**2.5**	**2.5**	**2.5**	**0.7**
2500	**2.0**	**2.0**	**2.0**	**0.5**

4.1. Gas pressure cycling test (pneumatic)

(a) **The CHSS is pressure cycled using hydrogen gas for total 500 cycles, which are divided into two groups of 250 cycles each according to the test parameters specified in Table 5a;**

The specified temperature and relative humidity is maintained within the test environment throughout each pressure cycle. When required in the test specification, the CHSS temperature is stabilized at the external environmental temperature between pressure cycles. If system controls that are active during vehicle service prevent the pressure from dropping below a specified pressure, the test cycles shall not go below that specified pressure;

The fuel delivery temperature shall conform to the specified range within 30 seconds of fuelling initiation;

(b) **The ramp rate for pressurization shall be greater than or equal to the linearly interpolated rate in Table 5b according to the CHSS volume; however, if the measured internal temperature in the CHSS container is greater than 85°C, then the pressure ramp rate shall be decreased;**

(c) **If devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature of the CHSS container, the test may be conducted with these devices and/or controls (or equivalent measures);**

(d) **The de-fuelling rate shall be greater than or equal to the intended vehicle's maximum fuel-demand rate. Out of the 500 pressure cycles, any fifty pressure cycles are performed using a de-fuelling rate greater than or equal to the maintenance de-fuelling rate**

specified by the manufacturer on CHSS container labelling or operating/maintenance manuals;

(e) The maximum allowable leak rate from the CHSS from a single point is in accordance with Annex 3, paragraph 4.3(b).

~~At the onset of testing, the storage system is stabilized at the specified temperature, relative humidity and fuel level for at least 24 hours. The specified temperature and relative humidity is maintained within the test environment throughout the remainder of the test. (When required in the test specification, the system temperature is stabilized at the external environmental temperature between pressure cycles.) The storage system is pressure cycled between less than 2 (+0/-1) MPa and the specified maximum pressure (±1 MPa). If system controls that are active in vehicle service prevent the pressure from dropping below a specified pressure, the test cycles shall not go below that specified pressure. The fill rate is controlled to a constant 3-minute pressure ramp rate, but with the fuel flow not to exceed 60 g/sec; the temperature of the hydrogen fuel dispensed to the container is controlled to the specified temperature. However, the pressure ramp rate should be decreased if the gas temperature in the container exceeds +85 °C. The defuelling rate is controlled to greater than or equal to the intended vehicle's maximum fuel-demand rate. The specified number of pressure cycles is conducted. If devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls (or equivalent measures).~~

4.2. Gas permeation test (pneumatic)

This test is performed after each group of 250 pneumatic pressure cycles conducted in accordance with Table 5a in Annex 3, paragraph 4.

~~A storage system~~ **The CHSS** is fully filled with hydrogen gas t**o ≥ 100 per cent SOC** ~~at 115 per cent NWP (+2/-0 MPa) (full fill density equivalent to 100 per cent NWP at +15 °C is 113 per cent NWP at +55 °C)~~ and **soaked for a minimum of 12 hours at 55 °C to 60 °C** ~~held at ≥ +55 °C~~ in a sealed ~~container~~ **chamber prior to the start of the test. The test shall continue until the permeation rate reaches a steady state based on at least 3 consecutive rates separated by at least 12 hours being within ±10 per cent of the previous rate, or 500 hours, whichever occurs first.** ~~until steady-state permeation or 30 hours, whichever is longer. The total steady-state discharge rate due to leakage and permeation from the storage system is measured.~~

4.3. Localized gas leak test (pneumatic)

A bubble test may be used to fulfil this requirement. The following procedure is used when conducting the bubble test:

(a) The exhaust of the shut-off valve (and other internal connections to hydrogen systems) shall be capped for this test (as the test is focused on external leakage).

At the discretion of the **Technical Service** ~~tester~~, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. The tester estimates the gas leakage based on the size and rate of bubble formation.

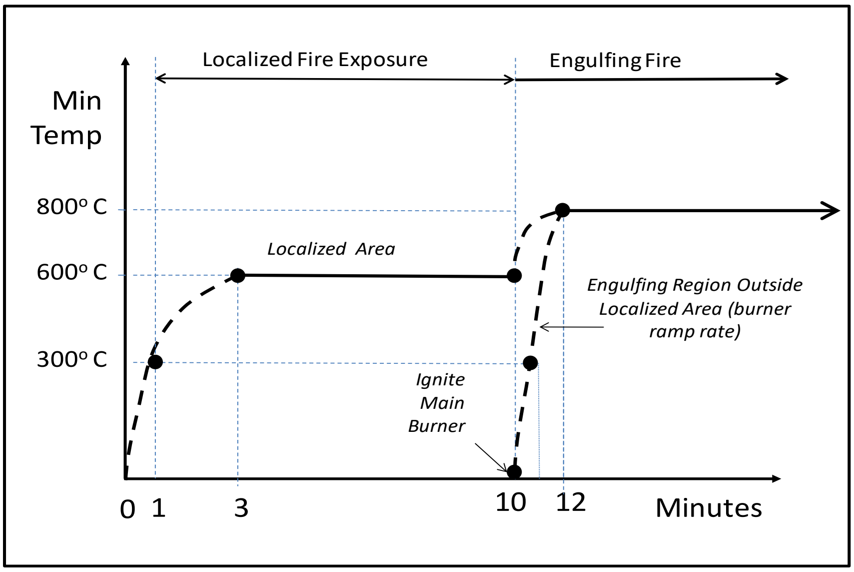
(b) ~~Note:~~ For a localized rate of 0.005 mg/sec (3.6 Nml/min), the resultant allowable rate of bubble generation is about 2,030 bubbles per minute for a typical bubble size of 1.5 mm in diameter. Even if much larger bubbles are formed, the leak **shall** ~~should~~ be readily detectable. For an unusually large bubble size of 6 mm in diameter, the allowable bubble rate would be approximately 32 bubbles per minute.

5. Test procedures for **two-stage localized/engulfing fire test** ~~service terminating performance in fire~~ (paragraph 5.4. of this Regulation)

~~5.1. Fire test~~

The test consists of two stages: a localized fire stage followed by an engulfing stage as described in Figure 4.

Figure 4
Temperature profile of fire test



The CHSS test article to be evaluated is defined in Annex 3, paragraph 5.1.

Test conditions and wind shielding requirements for conducting the fire test are defined in Annex 3, paragraph 5.2.

The fuel supply and burner for the fire test are defined in Annex 3, paragraph 5.3.

A pre-test checkout of the burner is defined in Annex 3, paragraph 5.4. to ensure that the burner is operating within the established thermal criteria prior to the CHSS fire test. This test is required when the conditions set forth in Annex 3, paragraph 5.4.1. indicate that the pre-test checkout is appropriate.

Final preparations for the CHSS fire test are defined in Annex 3, paragraphs 5.5 and 5.6, and the test procedure for the CHSS fire test under two-stage localized/engulfing fire test is defined in Annex 3, paragraph 5.7.

5.1. CHSS test article

In addition to the container and primary closure devices such as shut-off valve(s), check valve(s), and TPRD(s) required to isolate the system, the CHSS test article shall include container attachments (if any) including gas housings or barriers that could impede TPRD response. Vent lines shall be connected to TPRDs to direct TPRD exhausts in a manner representative of the configuration in the vehicle.

At the option of the manufacturer, the CHSS test article may include vehicle-specific structural framing, shields and panels, and/or other protective features intended to protect the CHSS from fire exposures consistent with the fire threats on the CHSS as installed in the specific vehicle.

5.2. Test conditions and wind shielding

Testing can be conducted either indoors or outdoors.

Ambient temperature and wind speed and direction shall be measured and recorded if testing conducted outdoors.

Outdoor testing shall not be conducted when precipitation (i.e., rain, snow, sleet, etc.) is occurring unless the test area with the test article and burner is protected such that the precipitation does not adversely affect the test result.

Wind shielding such as are walls, fencing, and/or enclosures shall be used for the fire tests at sites susceptible to wind effects during the tests (pre-test checkout and CHSS fire test). The wind shielding shall provide at least 0.5 m separation between the CHSS test article (or pre-test cylinder) and the wind shields such that the fire can freely draft and that the length of jet flames (if any) from the CHSS test article can be confirmed. Openings (or other provisions) shall be provided in wind shielding to allow fresh air to enter the test area and for the combustion products to be exhausted. The adequacy of wind shielding shall be verified by compliance to Table 10 during a pre-test check-out prior to the CHSS fire test.

NOTE: Rupture of container during the fire test is likely to result in blast waves and the rapid expulsion of container materials and attachments as well as the hydrogen contents.

These effects can result in uncontrolled movement of the CHSS test article and secondary explosions due to the build-up of high pressure, flammable gas mixtures within the test area and wind shielding (if used).

Countermeasures to these effects need to be addressed and implemented as part of locating the test site relative to other equipment and designing and constructing wind shielding (if used) and test support structure to prevent severe injury to personnel and unacceptable property damage.

5.3. Burner definition

In order to conduct the two-stage localized/engulfing fire test, the burner is divided into two zones:

(a) The localized burner zone operates by itself during the localized fire stage.

(b) **The engulfing burner extension simulates the spread of the fire from the localized burner zone to the remainder of the burner. The engulfing burner zone is comprised of both the localized burner zone and the engulfing fire extension.**

5.3.1. Fuel supply and burner control

The localized and engulfing burners shall be LPG-fired.

The LPG burner fuel flow to both the localized burner zone and engulfing burner extension shall be measured to set burner fuel flows to the specific heat release rates (HRR/As) defined in Annex 3, paragraph 5.4.5.

The measured fuel flow(s) shall be recorded throughout the test on a 1-second basis.

5.3.2. Burner configuration

5.3.2.1. The length of the localized burner zone (L_{LOC}) is 250 ± 50 mm.

The length of the engulfing burner extension (L_{EXT}) shall be a maximum of 1,400 ± 50 mm. A burner with the specified maximum extension can be used for all fire tests. Engulfing burner extensions shorter than the maximum are acceptable as long the burner extends beyond of the CHSS test article when positioned for the CHSS fire test.

The total length of the engulfing burner zone (L_{ENG}) is the sum L_{LOC} and L_{EXT}. The maximum value is 1,650 ± 100 mm based on the specifications above.

The width (W) of both the localized and engulfing burner zones shall be 500 ± 50 mm regardless of container width/ diameter.

The burner nozzle configuration and installation on the manifolds (or "rails") shall be consistent with Table 6. The number of nozzles (N_{LOC} and N_{EXT}) on the rails of the localized burner zone and the engulfing burner extension and the nozzle spacing (S_N) shall be selected such that the resultant lengths of the localized burner zone and the engulfing burner extension (L_{LOC} and L_{EXT}) meet requirements defined above. Similarly, the number of rails (N_R) and rail spacing (S_R) shall be selected such that the width of the burners meets requirements defined above.

NOTES:

(a) **The resultant lengths of the localized burner zone and the engulfing burner extension are determined by;**

$$L_{LOC} = N_{LOC} \times S_N$$

and

$$L_{EXT} = N_{EXT} \times S_N$$

based on selected values for the number of nozzles (N_{LOC} and N_{EXT} in the localized burner zone and the engulfing burner extension, respectively) and the nozzle spacing (S_N).

Similarly, the resultant width (W) of the burners is determined by;

$$W = (N_R - 1) \times S_R$$

based on selected values for number of rails (N_R) and rail spacing (S_R).

(b) As illustrated in Figure 6 below, the nozzles on the third and fourth rails aim toward the centre of the burner to form a "hot zone" in this targeted area.

Table 6
Definition of burner nozzles for the prescribed burner

Item	*Description*
Nozzle type	LPG fuel nozzle with air pre-mix
- LPG orifice in nozzle	1.0 ± 0.1 mm ID
- Air ports in nozzle	Four (4) holes, 6.4 mm ± 0.6 mm ID
- Fuel/Air mixing tube in nozzle	10 ± 1 mm ID
Number of Rails	6
Centre-to-centre Spacing of Rails	100 ± 10 mm
Centre-to-centre Nozzle Spacing Along the Rails	50 ± 5 mm

5.3.2.2. The values for L_{LOC}, L_{EXT}, and W defined above shall be used for calculating HRR/As for the localized burner zone and engulfing burner extension.

The borders of the localized burner zone and the engulfing burner extension shall be defined using L_{LOC}, L_{EXT}, and W so that test articles can be properly located and oriented for CHSS fire test. The borderline between the localized burner zone and the engulfing burner extension is located mid-way between the nozzles of the two zones and used as a datum for locating the outside borders at distances L_{LOC} and L_{EXT} away from the datum towards the localized burner zone and the engulfing burner extension, respectively. The centres of the outside rails of the burner zone(s) define the remaining two borders.

5.4. Pre-test checkout of burner

The purpose of the pre-test checkout is to verify that the localized and engulfing burner zones are operating as expected and that the test setup including wind shields are functional and capable of delivering repeatable results prior to conducting the CHSS fire tests.

5.4.1. Pre-test checkout frequency

This pre-test shall be performed at least once prior to conducting CHSS fire tests. If the burner and test setup is modified, then the pre-test shall be repeated before CHSS fire test.

5.4.2. Pre-test cylinder definition

A 320 mm diameter pre-test cylinder (fabricated from 300 mm/12 inch Schedule 40 NPS steel pipe with end caps) similar to vehicle fire tests shall be used for the burner pre-test.

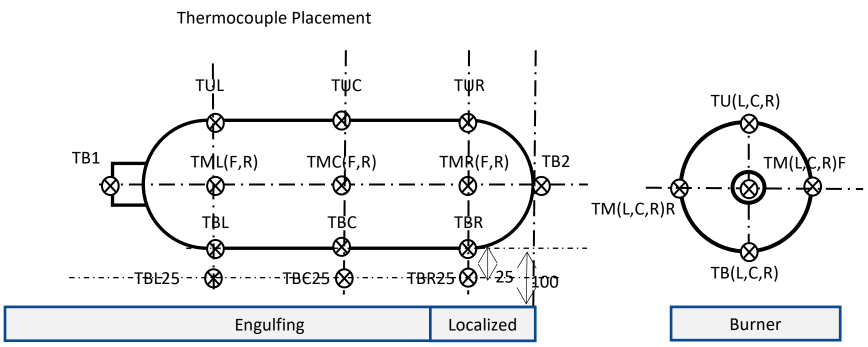
The cylindrical length of the pre-test cylinder shall be at least 800mm, and the overall length shall be equal or longer than the CHSS test article (up to maximum engulfing burner length in Annex 3, paragraph 5.1.1.).

5.4.3. **Instrumentation and data processing for pre-test check-out**

5.4.3.1. **The pre-test cylinder shall be instrumented to ensure that the burner and test setup will produce temperature levels consistent with performance-based requirements of the localized and engulfing fire zones. The location of the instrumentation shall be adjusted along the cylindrical section of the pre-test cylinder to be consistent with the targeted localized and engulfing fire zones of the CHSS test article. One set of instrumentation on the cylindrical section shall be centrally located within the localized zone, and the other two sets spread out over the remaining length of the engulfing fire zone (outside the localized fire zone).**

As an example of the process, Figure 5 illustrates a common situation where a container is protected by a TPRD on one end (i.e., the left end) so the localized fire zone is located on the right-end end. The surface temperatures are measured on the top, middle, and bottom of the pre-test cylinder in three locations along the length of the cylinder. The location on the right end of the cylindrical section is centrally-located in the targeted localized zone, and the other two locations are in the centre and left ends of the targeted engulfing fire zones along the cylindrical section.

Figure 5
Example of placement of instrumentation on the pre-test cylinder



Temperature measurements on the pre-test cylinder shall be performed by ϕ3.2 mm (or less) K-type sheath thermocouples that are located within a 5 mm gap from the pipe surface that are held on the surface by straps or other mechanical attachments. Temperature measurements shown in Figure 5 are defined as follows:

(a) **TBR, TBC, and TBL are temperature measurements on the bottom surface of the pre-test cylinder that are directly exposed to the burner flame.**

(b) **TMRF, TMCF, TMLF, TMRR, TMCR, and TMLR are temperature measurements on the surface of the pre-test cylinder at mid-height. These temperatures are used for data collection only during the pre-test verification and calibration of the localized and engulfing fires.**

(c) **TUR, TUC, and TUL are temperature measurements on the top surface of the pre-test cylinder that are opposite the side directly exposed to the burner flame.**

Additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes.

5.4.3.2. Thermocouples shall also be located 25 ± 5 mm below the pre-test cylinder along the length of the cylinder for the purpose of developing reference temperature levels during the pre-test checkout that can be subsequently used for monitoring the burner during the CHSS fire test. Three (3) thermocouples (TBR25, TBC25, and TBL25) shall correspond to pre-test cylinder instrumentation as shown in Figure 5. Thermocouples used to back up or supplement TBR25, TBC25, and TBL25 may also be added along the centre line of the burner. See paragraph 5.6. for requirements for positioning thermocouples for burner monitoring during the CHSS fire test.

The thermocouples used for burner monitoring shall be unshielded (i.e., unprotected by metal wells) ф3.2 mm (or less) K-type sheath thermocouples. Given the need to maintain the distance from the steel container within ± 5 mm, these thermocouples shall be mechanically supported to prevent movement or drooping. If testing of CHSSs with large width/diameters is contemplated, then mounting shall maintain the distance between the CHSS and the burner monitors as the spacing between the burner and CHSS is adjusted in paragraph 5.4.5.5.

5.4.3.3. Thermocouple readings shall be recorded at least once a second and then used to calculate the following parameters:

(a) TB_{LOC} is the bottom surface temperature of the pre-test cylinder based on TBR;

(b) TMF_{LOC} are the surface temperatures of the front side of the pre-test cylinder based on TMRF;

(c) TMR_{LOC} is the surface temperatures of the rear side of pre-test cylinder based on TMRR;

(d) TU_{LOC} is the top surface temperature of the pre-test cylinder based on TUR;

(e) TB_{LOC25} is the burner monitor below the pre-test cylinder (and subsequently below the CHSS test article in paragraph 5.6.) based on TBR25. Thermocouples used to back up or supplement TBR25 may also be included in the calculation of the average temperature of the burner monitors in the localized fire zone. Any thermocouple measurement that has been compromised or failed (or is not located within the localized fire zone) shall be disregarded from the calculation of average temperature of the burner monitor.

(f) TB_{ENG} is the bottom surface temperature of the pre-test cylinder based on the average of TBR, TBC, or TBL within the engulfing fire zone.

(g) TMF_{ENG} is the surface temperature of the front side of the pre-test cylinder based on the average of TMLF, TMCF, and TMRF within the engulfing fire zone.

(h) TMR_{ENG} is the surface temperatures of the rear side of the pre-test cylinder based on the average of TMLR, TMCR, and TMRR within the engulfing fire zone.

(i) TU_{ENG} is the top surface temperature of the pre-test cylinder based on the average of TUR, TUC, or TUL within the engulfing fire zone.

(j) TB_{ENG25} is the burner monitor below the pre-test cylinder (and subsequently below the CHSS test article in paragraph 5.6.) based on the average of the three required thermocouples (TBR25, TBC25, or TBL25 for the pre-test checkout) within the engulfing fire zone. Thermocouples used to back up or supplement TBR25, TBC25, or TBL25 may also be in included in the calculation of average temperature of the burner monitor in the engulfing fire zone. Any thermocouple measurement that has been compromised or failed (or is not located within the engulfing fire zone) shall be disregarded from the calculation of average temperature in the engulfing fire zone.

5.4.4. Mounting of the pre-test cylinder

The pre-test cylinder used for the pre-test checkout shall be mounted at a height of 100 ± 5 mm above the burner and located over the burner such that nozzles from the two centrally-located manifolds are pointing toward the bottom centre of the steel container.

NOTE: See the diagrams in Figure 6 and Figure 7 for examples of the mounting.

Figure 6
Description of instrumentation for the steel container used for pre-test checkout

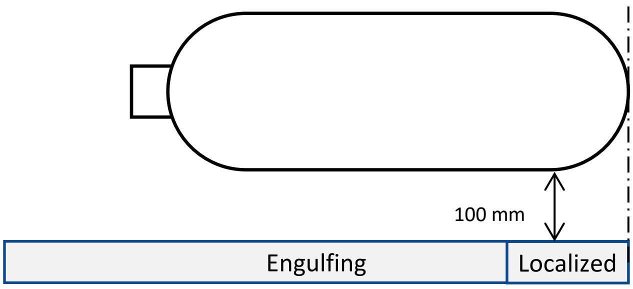
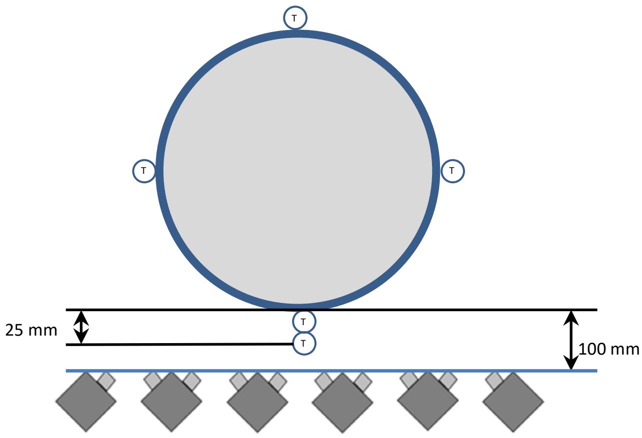


Figure 7
Position the bottom of the container relative to the burner



5.4.5. Pre-test checkout process

5.4.5.1. Prior to pre-test checkout of the burner, wind shieldings shall be installed in accordance with paragraph 5.2.

5.4.5.2. The burner shall, at a minimum, be operated at fuel flow setpoints that match the settings intended for the localized and engulfing burners during the CHSS fire test. Suggested settings for the burners are provided in Table 7; however, any setting within the allowable ranges of HRR/A in Table 7 may be selected.

NOTE: During the engulfing fire stage, both the localized burner and the engulfing burner extension need to be set to the intended HRR/A for uniform heat release from the engulfing burner.

Table 7
Allowable range of operation and the suggested settings for the prescribed burner

Fire Stage	*Allowable Range of Specific Heat Release Rate (HRR/A)*	*Suggested Setting of Specific Heat Release Rate (HRR/A)*
Localized Burner	**200 - 500 kW/m^2**	**300 kW/m^2**
Engulfing Burner	**400 - 1000 kW/m^2**	**700 kW/m^2**

5.4.5.3. The 60-second rolling averages of individual temperature readings in the localized fire zone (i.e., TB_{LOC}, TMF_{LOC}, TMR_{LOC}, and TU_{LOC}) and the engulfing fire zone (i.e., TBR, TBC, TBL, TMRF, TMCF, TML, TMRR, TMCR, TMLR, TUR, TUC, and TUL) shall be in accordance with Table 8 at the HRR/A settings selected for the CHSS fire test in paragraph 5.7.

Table 8
Criteria for acceptance of localized and engulfing burners using alternative burner configurations

Fire Stage	*Allowable Temperature Range on Bottom of Pre-test cylinder*	*Allowable Temperature Range on Sides of Pre-test cylinder*	*Allowable Temperature Range on Top of Pre-test cylinder*
Localized Burner	**450 °C < TB_{LOC} < 750 °C**	**TMF_{LOC} < 750 °C and TMR_{LOC} < 750 °C**	**TU_{LOC} < 300 °C**
Engulfing Burner	**TB_{ENG} > 600 °C**		**TU_{ENG} > 100 °C and TU_{ENG} < TB_{ENG} when TU_{ENG} > 750 °C**

5.4.5.4. Additionally, the allowable limits for the burner monitors during subsequent CHSS fire test shall be established based on test results at the expected localized and engulfing burner settings during the pre-test checkout:

(a) The minimum value for the burner monitor during the localized fire stage ($Tmin_{LOC25}$) shall be calculated by subtracting 50 °C from the 60-second rolling average of TB_{LOC25}. If the resultant minimum values exceed 600 °C, the minimum value is set to 600 °C for the localized fire stage.

(b) The minimum value for the burner monitor during the engulfing fire stage ($Tmin_{ENG25}$) shall be calculated by subtracting 50 °C from the 60-second rolling average of TB_{ENG25}. If the resultant minimum values exceed 800 °C, the minimum value is set to 800 °C for the engulfing fire stage.

If the above requirements are satisfactorily met, then the burner setup is typically ready for CHSS fire test.

5.4.5.5. If results are not satisfactory, then the source of the variation in burner performance shall be identified and corrected and then re-tested until the requirements for pre-test verification are met. Adjustment of the height is permissible to achieve acceptable operation within the allowable operating ranges as defined in Tables 7 and 8.

When the width/diameter of the CHSS test article is larger than the width of the burner and the shape of the bottom of the CHSS test article impedes the burner exhaust from readily flowing up and around the CHSS test article during the CHSS fire test, then the burner air flow can be restricted and the burner monitors may not be able to achieve the required minimum temperatures during the localized and/or engulfing fire stages of the CHSS fire test. If the CHSS test article is expected to impede the burner flow (or if the burner monitors did not achieve the required temperatures during the CHSS fire test), then the following additional pre-test is required to determine the appropriate height for mounting the CHSS test article above the burner such that required temperatures are achieved:

(a) A pre-test plate (made of steel) with approximately the length and width/diameter of the CHSS test article is mounted above the burner to simulate the bottom on the CHSS test article at an initial height of 100 mm.

(b) Burner monitors as defined in Annex 3, paragraph 5.4.3.2. are located 25 ± 5 mm below the surface.

(c) The burners are operated in the localized and engulfing modes (at the HRR/As established above) and the temperatures of the burner monitors are measured.

(d) If the burner monitors for both the localized and engulfing fire stages do not meet the minimum criteria (defined in Annex 3, paragraph 5.4.5.4.), then the height of the pre-test plate above the burner shall be increased by 50 mm and the process in steps 2 and 3 are repeated until a satisfactory height if achieved.

NOTE: Satisfactory results are expected at heights of 200 – 250 mm.

If the burner monitors meet the minimum criteria (defined above) for both the localized and engulfing fire stages, then the required height for locating the CHSS test article above the burner has been determined and the pre-test is complete.

5.5. **Mounting of the CHSS test article above the burner**

After the pre-test checkout(s) have been satisfactorily completed, the CHSS test article shall be mounted above the burner.

5.5.1. **Height and location of the CHSS test article above the burner**

The CHSS test article shall be mounted at the same height above the burner as for the pre-test checkout in Annex 3, paragraph 5.4. and located over the burner such that nozzles on the two centrally-located manifolds (or "rails") are pointing toward the targeted region on the bottom (i.e., the lowest elevation) of the CHSS test article. See Figures 8 and 9 for examples of the mounting of cylindrical and conformable containers, respectively.

Figure 8
Position the bottom of the cylindrical container relative to the burner

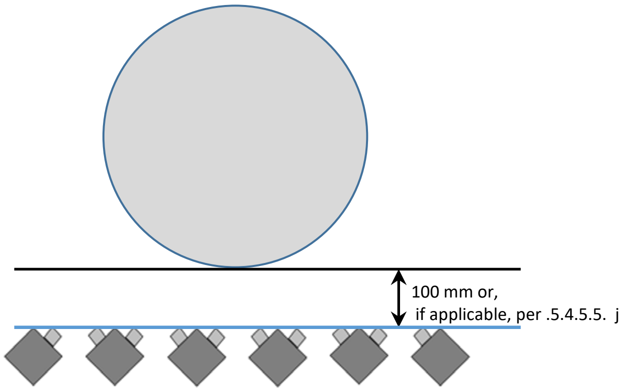
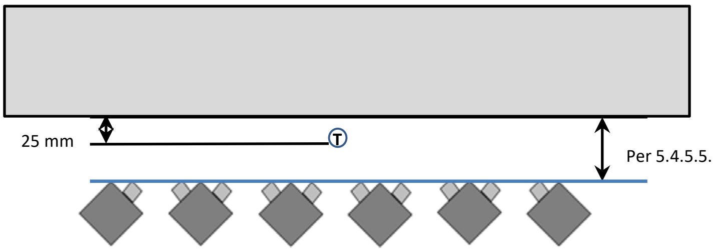


Figure 9
Position the bottom of the conformable container relative to the burner



5.5.2. **Targeting of the localized and engulfing burner zones on the CHSS**

Localized fire shall be targeted on the CHSS test article to challenge the ability of the TPRDs to sense the fire and respond in order to protect the container. This requirement is met as follows:

(a) For CHSS where the manufacturer has not opted to include vehicle-specific features (as defined in paragraph 5.1.), the CHSS test article shall be rotated relative to the localized burner to minimize the ability to TPRDs to sense the fire and respond. Shields, panels, wraps, structural elements, and other features

added to the container shall be considered when establishing the worst case orientation relative to the localized fire as parts and features intended to protect sections of the container but can (inadvertently) leave other potions or joints/seams vulnerable to attack and/or hinder the ability of TPRDs to respond.

For CHSS where the manufacturer has opted to include vehicle-specific features (as defined in Annex 3, paragraph 5.1.), the CHSS test article is oriented relative to the localized burner to provide the worst case fire exposure identified for the specific vehicle.

(b) The localized burner shall be located under the CHSS test article such that the distance from localized fire zone to the nearest TPRD sense point(s) is maximized.

The engulfing fire zone shall extend in one direction from the localized fire zone toward the nearest TPRD (or sense point). The engulfing burner can extend beyond the TPRD(s) if the distance from the localized burner is less than the maximum allowable extension of the engulfing burner as defined above (i.e., 1,400 ± 50 mm).

5.6. Instrumentation and connections to the CHSS test article

5.6.1. The definition and mounting of the thermocouples for burner monitoring are analogous to Annex 3, paragraph 5.4.3.2. for the pre-test checkout. See Figures 8 and 9 for examples of the mounting below cylindrical and conformable containers, respectively.

At least one thermocouple for burner monitoring shall be located in the localized fire exposure of the CHSS test article, and two thermocouples shall be located in the extension of the engulfing fire exposure on the CHSS test article. Additional thermocouples may be added to back up or supplement burner monitoring along the centre line of the localized and engulfing burners.

5.6.2. The calculation of the burner monitor temperatures (TB_{LOC25} and TB_{ENG25}) are analogous to the process in Annex 3, paragraph 5.4.3.3. for the pre-test checkout.

Additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes.

A fluid line shall be connected to the CHSS prior to test to allow fill and vent of the CHSS as defined within the test procedure.

Shut-off(s) valves shall be installed on the line as required to isolate the CHSS contents during the test and perform required fill and vent procedures prior to or after the test.

A pressure transmitter shall also be installed on the line such that the pressure of contents within the CHSS can be remotely monitored during the test. The accuracy of the transmitter shall be at least ±1 per cent of full scale and ±10 per cent at 1 MPa.

5.7. The CHSS fire test procedure

5.7.1. Prior to conducting the CHSS fire test, the CHSS shall be filled with compressed hydrogen gas to ≥ 100 per cent of state-of-charge (SOC).

5.7.2. The first stage of the CHSS fire test is initiated by starting the fuel flow to the localized burner and igniting the burner:

(a) After ignition is confirmed, the fuel flow is set to the value that matches the desired specific heat release rate (HRR/A) for the localized burner in Annex 3, paragraph 5.4.5.3., and the test time is set to 0 minutes.

(b) As shown in Figure 4 in Annex 3, paragraph 5., the 10-second rolling average of the burner monitor in the localized fire zone (TB_{LOC25}) shall be at least 300 °C within 1 minute of ignition and for the next 2 minutes.

Within 3 minutes of start, the 60-second rolling average of the localized burner monitor (TB_{LOC25}) shall be greater than $Tmin_{LOC25}$ as determined in Annex 3, paragraph 5.4.5.4. If TB_{LOC25} does not achieve the required temperature within 3 minutes, the test is terminated.

NOTES:

(i) Monitoring of the 60-second rolling average of the localized burner monitor (TB_{LOC25}) is not required after the above criteria are met as the burner monitor readings may be compromised by expansion or falling of materials from the CHSS test article during subsequent CHSS fire test.

(ii) The temperature outside the region of the localized fire exposure is not specified during these initial 10 minutes from the time of ignition.

(iii) If the test is terminated because TB_{LOC25} did not achieve required temperature within the required time, requirements in Annex 3, paragraph 5.2. for providing wind shielding and paragraph 5.4.5. for adjusting the burner operation and setup should be considered prior to re-test.

5.7.3. After 10 minutes from start of test, the second stage is initiated by starting fuel flow to the engulfing burner extension and igniting the burner:

(a) After ignition is confirmed, the fuel flowrates to both the localized and engulfing fire extension are set to the value that matches the desired specific heat release (HRR/A) for the engulfing burner stage in Annex 3, paragraph 5.4.5.3.

(b) Within 2 minutes of the start of ignition of the engulfing burner (i.e., within 12 minutes from start of test), the 60-second rolling average of the engulfing burner monitor (TB_{ENG25}) shall be equal or greater than $Tmin_{ENG25}$ as determined in Annex 3, paragraph 5.4.5.4.

NOTES:

(i) Monitoring of the 60-second rolling average of the engulfing burner monitor (TB_{ENG25}) is not required after the above criteria are met as the burner monitor readings may be compromised by expansion or falling of materials from the CHSS test article during subsequent CHSS fire test.

(ii) If the test is terminated because TB_{ENG25} did not achieve required temperature within the required time, requirements in Annex 3, paragraph 5.2. for providing wind

shielding and Annex 3, paragraph 5.4.5. for adjusting the burner operation and setup should be considered prior to re-test.

5.7.4. **Minor movement of the CHSS test article and subsequent repositioning of the CHSS test article relative to the burners is allowed when TPRD(s) activate.**

The fire test continues until either;

(a) the CHSS vents and the pressure falls to less than 1 MPa; or

(b) a total test of 1 hour from start of test is reached for CHSS in LDV or 2 hours for CHSS in HDV.

When the test is completed, the burner fuel flow shall be shut off within 1 minute, and the CHSS shall be depressurized (if not already near ambient pressure) and then purged with inert gas for safe post-test handling.

~~The hydrogen container assembly consists of the compressed hydrogen storage system with additional relevant features, including the venting system (such as the vent line and vent line covering) and any shielding affixed directly to the container (such as thermal wraps of the container(s) and/or coverings/barriers over the TPRD(s)).~~

~~Either one of the following two methods are used to identify the position of the system over the initial (localized) fire source:~~

~~(a) Method 1: Qualification for a generic (non-Specific) vehicle installation~~

~~If a vehicle installation configuration is not specified (and the type approval of the system is not limited to a specific vehicle installation configuration) then the localized fire exposure area is the area on the test article farthest from the TPRD(s). The test article, as specified above, only includes thermal shielding or other mitigation devices affixed directly to the container that are used in all vehicle applications. Venting system(s) (such as the vent line and vent line covering) and/or coverings/barriers over the TPRD(s) are included in the container assembly if they are anticipated for use in any application. If a system is tested without representative components, retesting of that system is required if a vehicle application specifies the use of these type of components.~~

~~(b) Method 2: Qualification for a specific vehicle installation~~

~~If a specific vehicle installation configuration is specified and the type approval of the system is limited to that specific vehicle installation configuration, then the test setup may also include other vehicle components in addition to the hydrogen storage system. These vehicle components (such as shielding or barriers, which are permanently attached to the vehicle's structure by means of welding or bolts and not affixed to the storage system) shall be included in the test setup in the vehicle-installed configuration relative to the hydrogen storage system. This localized fire test is conducted on the worst case localized fire exposure areas based on the four fire orientations: fires originating from the direction of the passenger compartment, luggage compartment, wheel wells or ground-pooled gasoline.~~

5.1.1. The container may be subjected to engulfing fire without any shielding components, as described in Annex 3, paragraph 5.2.

5.1.2. The following test requirements apply whether Method 1 or 2 (above) is used:

(a) The container assembly is filled with compressed hydrogen gas at 100 per cent of NWP (+2/-0 MPa). The container assembly is positioned horizontally approximately 100 mm above the fire source;

(b) Localized portion of the fire test:

(i) The localized fire exposure area is located on the test article furthest from the TPRD(s). If Method 2 is selected and more vulnerable areas are identified for a specific vehicle installation configuration, the more vulnerable area that is furthest from the TPRD(s) is positioned directly over the initial fire source;

(ii) The fire source consists of LPG burners configured to produce a uniform minimum temperature on the test article measured with a minimum 5 thermocouples covering the length of the test article up to 1.65 m maximum (at least 2 thermocouples within the localized fire exposure area, and at least 3 thermocouples equally spaced and no more than 0.5 m apart in the remaining area) located 25 (±10) mm from the outside surface of the test article along its longitudinal axis. At the option of the manufacturer or testing facility, additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes;

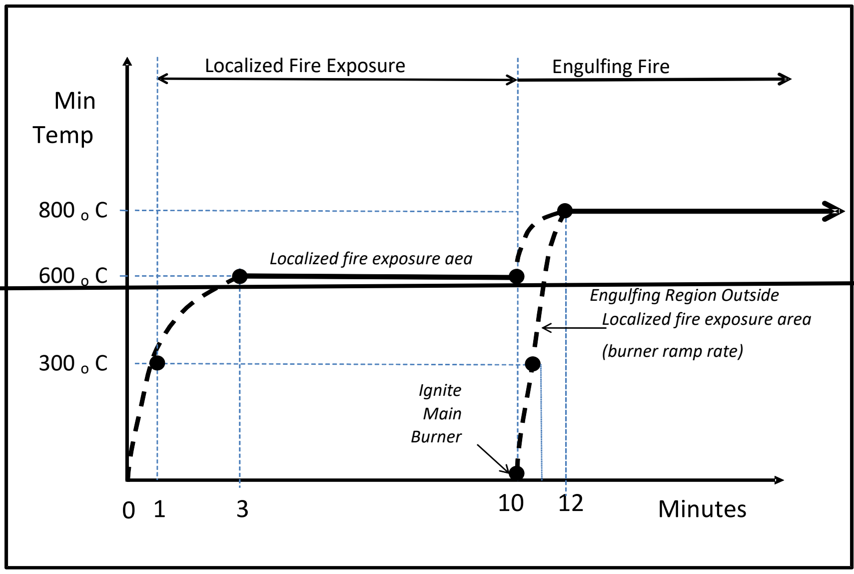
(iii) Wind shields are applied to ensure uniform heating;

(iv) The fire source initiates within a 250 (±50) mm longitudinal expanse positioned under the localized fire exposure area of the test article. The width of the fire source encompasses the entire diameter (width) of the storage system. If Method 2 is selected, the length and width shall be reduced, if necessary, to account for vehicle-specific features;

(v) As shown in Figure 3 the temperature of the thermocouples in the localized fire exposure area has increased continuously to at least 300 °C within 1 minute of ignition, to at least 600 °C within 3 minutes of ignition, and a temperature of at least 600 °C is maintained for the next 7 minutes. The temperature in the localized fire exposure area shall not exceed 900 °C during this period. Compliance to the thermal requirements begins 1 minute after entering the period with minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple in the region of interest. (*Note*: The temperature outside the region of the initial fire source is not specified during these initial 10 minutes from the time of ignition.).

Figure 3

Temperature profile of fire test



(c) Engulfing portion of the fire test

Within the next 2 minute interval, the temperature along the entire surface of the test article shall be increased to at least 800 °C and the fire source is extended to produce a uniform temperature along the entire length up to 1.65 m and the entire width of the test article (engulfing fire). The minimum temperature is held at 800 °C, and the maximum temperature shall not exceed 1,100 °C. Compliance to thermal requirements begins 1 minute after entering the period with constant minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple.

The test article is held at temperature (engulfing fire condition) until the system vents through the TPRD and the pressure falls to less than 1 MPa. The venting shall be continuous (without interruption), and the storage system shall not rupture. An additional release through leakage (not including release through the TPRD) that results in a flame with length greater than 0.5 m beyond the perimeter of the applied flame shall not occur.

Table 1
Summary of fire test protocol

-	*Localized Fire Region*	*Time Period*	*Engulfing Fire Region (Outside the Localized Fire Region)*
Action	Ignite Burners	0-1 Minute	No Burner Operation
Minimum temperature	Not specified	-	Not specified
Maximum temperature	Less than 900 °C	-	Not specified
Action	Increase temperature and stabilize fire for start of localized fire exposure	1-3 Minutes	No Burner Operation
Minimum temperature	Greater than 300 °C	-	Not specified
Maximum temperature	Less than 900 °C	-	Not specified
Action	Localized fire exposure continues		No Burner Operation
Minimum temperature	1-minute rolling average greater than 600 °C		Not specified
Maximum temperature	1-minute rolling average less than 900 °C	3-10 Minutes	Not specified
Action	Increase temperature		Main Burner Ignited at 10 minutes
Minimum Temperature	1-minute rolling average greater than 600 °C		Not specified
Maximum temperature	1-minute rolling average less than 1,100 °C	10-11 Minutes	Less than 1,100 °C
Action	Increase temperature and stabilize fire for start of engulfing fire exposure		Increase temperature and stabilize fire for start of engulfing fire exposure
Minimum temperature	1-minute rolling average greater than 600 °C		Greater than 300 °C
Maximum temperature	1-minute rolling average less than 1,100 °C	11-12 Minutes	Less than 1,100 °C
Action	Engulfing fire exposure continues		Engulfing fire exposure continues
Minimum temperature	1-minute rolling average greater than 800 °C		1-minute rolling average Greater than 800 °C
Maximum temperature	1-minute rolling average less than 1,100 °C	12 Minutes - end of test	1-minute rolling average less than 1,100 °C

(d) Documenting results of the fire test

The arrangement of the fire is recorded in sufficient detail to ensure the rate of heat input to the test article is reproducible. The results include the elapsed time from ignition of the fire to the start of venting through the TPRD(s), and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached. Thermocouple temperatures and container pressure are recorded at intervals of every 10 sec or less during the test. Any failure to maintain specified minimum temperature requirements based on the 1-minute rolling averages invalidates the test result. Any failure to maintain specified maximum temperature requirements based on the 1-minute rolling averages invalidates the test result only if the test article failed during the test.

5.2. Engulfing fire test:

The test unit is the compressed hydrogen storage system. The storage system is filled with compressed hydrogen gas at 100 per cent NWP (+2/-0 MPa). The container is positioned horizontally with the container bottom approximately 100 mm above the fire source. Metallic shielding is used to prevent direct flame impingement on container valves, fittings, and/or pressure relief devices. The metallic shielding is not in direct contact with the specified fire protection system (pressure relief devices or container valve).

A uniform fire source of 1.65 m length provides direct flame impingement on the container surface across its entire diameter. The test shall continue until the container fully vents (until the container pressure falls below 0.7 MPa). Any failure or inconsistency of the fire source during a test shall invalidate the result.

Flame temperatures shall be monitored by at least three thermocouples suspended in the flame approximately 25 mm below the bottom of the container. Thermocouples may be attached to steel cubes up to 25 mm on a side. Thermocouple temperature and the container pressure shall be recorded every 30 seconds during the test.

Within five minutes after the fire is ignited, an average flame temperature of not less than 590 °C (as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval) is attained and maintained for the duration of the test.

If the container is less than 1.65 m in length, the centre of the container shall be positioned over the centre of the fire source. If the container is greater than 1.65 m in length, then if the container is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the container. If the container is greater than 1.65 m in length and is fitted with pressure relief devices at both ends, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

The container shall vent through a pressure relief device without bursting. "

Annex 4 (all paragraphs and Appendix)., amend to read:

"Annex 4

Test procedures for specific components for the compressed hydrogen storage system

Testing is performed with either hydrogen or non-reactive gas as specified in the following paragraphs:

Hydrogen gas shall be compliant with ISO 14687:2019, SAE J2719_202003, or meet the following specifications:

(a) Hydrogen fuel index: ≥ 99.97%

(b) Total non-hydrogen gases: ≤ 300 µmol/mol

(c) Water: ≤ 5 µmol/mol

(d) Particle concentrations: ≤ 1 mg/kg

The leak test gas shall be hydrogen, helium, or a non-reactive gas mixture containing a detectable amount of helium or hydrogen gas.

All tests are performed at ambient temperature of 20 ± 5 °C unless otherwise specified.

1. TPRD Qualification Performance Tests

~~Testing is performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests are performed at ambient temperature 20 (±5) °C unless otherwise specified.~~ The TPRD qualification performance tests are specified as follows (see also Appendix 1):

1.1. Pressure cycling test.

Five TPRD units undergo ~~11,000 internal pressure cycles for a 15-year service life or~~ 15,000 internal pressure cycles **according to Table 1.** ~~for a 20-year service life with hydrogen gashaving gas quality compliant with ISO 14687-2/SAE J2719. The first five pressure cycles are between 2 (±1) MPa and 150 per cent NWP (±1 MPa); the remaining cycles are between 2 (±1) MPa and 125 per cent NWP (±1 MPa). The first 1,500 pressure cycles are conducted at a TPRD temperature of 85 °C or higher. The remaining cycles are conducted at a TPRD temperature of 55 (±5) °C. The maximum pressure cycling rate is ten cycles per minute.~~ Following this test, the pressure relief device shall comply **with** the requirements of the **l**eak test (Annex 4, paragraph 1.8.), **the bench top activation test (Annex 4, paragraph 1.9.)** and **f**low rate test (Annex 4, paragraph 1.10.) ~~and Bench top activation test (Annex 4, paragraph 1.9.)~~. **See Table 1 below for a summary of the pressure cycles.**

Table 1
Pressure cycling conditions

Pressure cycles to per cent NWP	*No. of cycles*	*Sample temperature for cycling*
≤ 2 MPa to ≥ 150 per cent NWP	**First 10**	**≥ 85 °C**
≤ 2 MPa to ≥ 125 per cent NWP	**Next 2, 240**	**≥ 85 °C**
≤ 2 MPa to ≥ 125 per cent NWP	**Next 10,000**	**20 °C**
≤ 2 MPa to ≥ 80 per cent NWP	**Next 2,750**	**≤ -40 °C**
Note: All cycles are conducted at a rate of ≤ 10 cycles per minute.		

1.2. Accelerated life test.

Eight TPRD units undergo testing; three at the manufacturer's specified activation temperature, **T_{act}** ~~Tact~~, and five at an accelerated life temperature**. The Accelerated Life test temperature is T_L, given in °C by the expression:**

~~;~~

$$T_L = \left(\frac{0.502}{\beta + T_f} + \frac{0.498}{\beta + T_{ME}}\right)^{-1} - \beta$$

Where β = 273.15, T_{ME} is 85 °C, and T_f is the manufacturer's specified activation temperature.

~~Tlife = 9.1 x Tact^0.503^.~~ The TPRD is placed in an oven or liquid bath with the temperature held constant (±1 °C). The ~~hydrogen gas~~ pressure on the TPRD inlet is ≥ 125 per cent NWP ~~(±1 MPa)~~. The pressure supply may be located outside the controlled temperature oven or bath. Each device is **pressurized** ~~pressured~~ individually or through a manifold system. If a manifold system is used, each pressure connection **may include** ~~includes~~ a check valve to prevent pressure depletion of the system when one specimen fails. The three TPRDs tested at **T_{act}**~~Tact~~ shall activate in less than **10** ~~ten~~ hours. The five TPRDs tested at **T_L** ~~Tlife~~ shall not activate in less than 500 hours **and shall meet the requirements of Annex4, paragraph 1.8. (Leak test)**.

1.3. Temperature cycling test

(a) An unpressurized TPRD is placed in a liquid bath maintained at ≤ -40 °C ~~or lower~~ **for** at least two hours. The TPRD is transferred to a liquid bath maintained at ≥ +85 °C ~~or higher~~ within five minutes, and maintained at that temperature at least two hours. The TPRD is transferred to a liquid bath maintained at ≤ -40 °C ~~or lower~~ within five minutes;

(b) Step (a) is repeated until 15 thermal cycles have been achieved;

(c) With the TPRD conditioned for **at least** ~~a minimum of~~ two hours in the ≤ -40 °C ~~or lower~~ liquid bath, the internal pressure of the TPRD is cycled with hydrogen **or inert** gas between ≤ 2 MPa ~~(+1/-0 MPa)~~ and ≥ 80 per cent NWP ~~(+2/-0 MPa)~~ for 100 cycles while the liquid bath is maintained at ≤ -40 °C ~~or lower~~;

(d) Following the thermal and pressure cycling, the pressure relief device shall comply with the requirements of Leak test (Annex 4, paragraph 1.8.), except that the Leak test shall be conducted at ≤ -40 °C ~~(+5/-0 °C)~~. After the ~~Leak~~ **leak** test, the TPRD shall comply with the requirements of ~~Bench~~ **the bench** top activation test (Annex 4, paragraph 1.9.) and then ~~Flow~~ **the flow** rate test (Annex 4, paragraph 1.10.).

1.4. Salt corrosion resistance test

Accelerated cyclic corrosion shall be performed in accordance with the following procedure:

(a) Three TPRDs shall be exposed to an accelerated laboratory corrosion test, under a combination of cyclic conditions (salt solution, various temperatures, humidity, and ambient environment). The test method is comprised of 1 per cent (approximate) complex salt mist applications coupled with high temperature, high humidity and high temperature dry off. One test cycle is equal to 24 hours, as illustrated in Table 2.

Table 2
Accelerated Cyclic Corrosion Conditions (1 cycle = 24 h)

Cycle Condition	*Temperature (°C)*	*Relative Humidity (%)*	*Cycle Duration)*
Ambient stage	**25 ± 3**	**45 ± 10**	**8 h ± 10 min**
Transition 1 h ± 5 min			
Humid stage	**49 ± 2**	**100 +0/-20**	**7 h ± 10 min**
Transition 3 h ± 10 min			
Dry stage	**60 ± 2**	**≤ 30**	**5 h ± 10 min**

(b) The apparatus used for this test shall consist of a fog/environmental chamber, suitable water supply conforming to ASTM D1193-06(2018) Type IV, provisions for heating the chamber, and the necessary means of controlling temperature between 22 °C and 62 °C. The apparatus shall include provisions for a supply of suitably conditioned compressed air and one or more nozzles for fog generation. The nozzle or nozzles used for the generation of the fog shall be directed or baffled to minimize any direct impingement on the test samples.

(c) The apparatus shall consist of the chamber design as defined in ISO 6270-2:2017. During "wet-bottom" generated humidity cycles, the proper wetness shall be confirmed by visual inspection of visible water droplets on the samples.

(d) Steam generated humidity may be used provided the source of water used in generating the steam is free of corrosion inhibitors. During steam generated humidity cycles, the testing agency must confirm that visible water droplets are found on the samples to verify proper wetness.

(e) The apparatus for the dry off stage shall have the ability to obtain and maintain the following environmental conditions:

temperature: 60 ± 2 °C and humidity: ≤ 30 per cent RH. The apparatus shall also have sufficient air circulation to prevent temperature stratification, and also allow thorough drying of the test samples.

(f) **The force/impingement from this salt application shall not remove corrosion or damage the coatings/paints system of test samples.**

(g) **The complex salt solution in percent by mass shall be as specified below:**

(i) Sodium Chloride (NaCl): 0.9 per cent

(ii) Calcium Chloride ($CaCl_2$): 0.1 per cent

(iii) Sodium Bicarbonate ($NaHCO_3$): 0.075 per cent

Sodium Chloride must be reagent grade or food grade. Calcium Chloride must be reagent grade. Sodium Bicarbonate must be reagent grade or food grade (e.g., Baking Soda or comparable product is acceptable). Water must meet ASTM D1193-06(2018) Type IV requirements.

NOTE: Either $CaCl_2$ or $NaHCO_3$ material must be dissolved separately in water and added to the solution of the other materials. If all solid materials are added dry, an insoluble precipitate may result.

(h) **The TPRD shall be installed in accordance with the manufacturer's recommended procedure and exposed to the cyclic corrosion test method described in Table 2.**

(i) **Repeat the cycle daily until 100 cycles of exposure have been completed. For each salt mist application, the solution shall be sprayed as an atomized mist, using the spray apparatus to mist the components until all areas are thoroughly wet / dripping. Suitable application techniques include using a plastic bottle, or a siphon spray powered by oil-free regulated air to spray the test samples. The quantity of spray applied shall be sufficient to visibly rinse away salt accumulation left from previous sprays. A total of four salt mist applications shall be applied during the ambient stage. Salt mist is not applied during any other stage of the test. The first salt mist application occurs at the beginning of the ambient stage. Each subsequent salt mist application shall be applied approximately ninety minutes after the previous application in order to allow adequate time for test sample to dry. If the test must be interrupted for weekends and holidays, the test article shall be kept at the ambient temperature of 25 ± 3 °C and the relative humidity of 45 ± 10 per cent and the cycle shall restart from ambient stage.**

(j) **Humidity ramp times between the ambient and wet condition, and between the wet and dry conditions, can have a significant effect on test acceleration (this is because corrosion rates are highest during these transition periods). The time from ambient to the wet condition shall be 60 ± 5 minutes and the transition time between wet and dry conditions shall be 180 ± 10 minutes.**

(k) **Immediately after the corrosion test, the samples are rinsed with fresh tap water and allowed to dry before evaluating.**

(l) **The TPRDs shall then comply with the requirements of the leak test (Annex 4, paragraph 1.8.), bench top activation test (Annex 4, paragraph 1.9.) and flow rate test (Annex 4, paragraph 1.10.).**

~~Two TPRD units are tested. Any non-permanent outlet caps are removed. Each TPRD unit is installed in a test fixture in accordance with the manufacturer's recommended procedure so that external exposure is consistent with realistic installation. Each unit is exposed for 500 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus) except that in the test of one unit, the pH of the salt solution shall be adjusted to 4.0 ± 0.2 by the addition of sulphuric acid and nitric acid in a 2:1 ratio, and in the test of the other unit, the pH of the salt solution shall be adjusted to 10.0 ± 0.2 by the addition of sodium hydroxide. The temperature within the fog chamber is maintained at 30-35 °C).~~

~~Following these tests, each TPRD pressure relief device shall comply with the requirements of Leak test (Annex 3, paragraph 6.1.8.), Flow rate test (Annex 3, paragraph 6.1.10.) and Bench top activation test (Annex 3, paragraph 6.1.9.).~~

1.5. Vehicle environment test

Resistance to degradation by external exposure to automotive fluids is determined by the following test:

(a) The inlet and outlet connections of the TPRD are connected or capped in accordance with the manufacturers installation instructions. The external surfaces of the TPRD are exposed for 24 hours at **ambient temperature** ~~20 (±5) °C~~ to each of the following fluids:

(i) Sulphuric acid (19 per cent solution by volume in water);

(ii) **Ethanol/gasoline – 10 per cent/90 per cent concentration of E10 fuel; and** ~~Sodium hydroxide (25 per cent solution by weight in water);~~

(iii) ~~Ammonium nitrate (28 per cent by weight in water); and~~

~~(iv)~~ Windshield washer fluid (50 per cent by volume methyl alcohol and water).

The fluids are replenished as needed to ensure complete exposure for the duration of the test. A distinct test is performed with each of the fluids. One **TPRD shall** ~~component may~~ be used for exposure to all of the fluids in sequence.

(b) After exposure to each fluid, the **TPRD** ~~component~~ is wiped off and rinsed with water;

(c) The **TPRD** ~~component~~ shall not show signs of physical degradation that could impair the function of the **TPRD** ~~component~~, specifically: cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not failures. At the conclusion of all exposures, the **TPRD** ~~unit(s)~~ shall comply with the requirements of **the leak** test (Annex 4, paragraph 1.8.), **bench top activation test (Annex 4, paragraph 1.9.) and flow** rate test (Annex 4, paragraph 1.10.) ~~and Bench top activation test (Annex 4, paragraph 1.9.)~~.

1.6. Stress corrosion cracking test.

This test is applicable to TPRDs containing copper alloys exposed to the outside environment.

For TPRDs containing components made of a copper~~-based~~ alloy (e.g. brass), one TPRD unit is tested. All copper alloy components exposed to the atmosphere shall be degreased and then continuously exposed for **at least** ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover.

Aqueous ammonia having a specific gravity of 0.94 is maintained at the bottom of the glass chamber below the sample at a concentration of at least 20 ml per litre of chamber volume. The sample is positioned 35 ± **5**~~(±5)~~ mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture is maintained at atmospheric pressure at 35 ± **5** ~~(±5)~~ °C. Copper-~~based~~ alloy components shall not exhibit cracking or delaminating due to this test.

1.7. Drop and vibration test

(a) ~~Six~~ TPRD units **representative of their final assembled form** are dropped from a height of 2 m **or greater without restricting its motion as a result of gravity,** at ambient temperature~~ (20 ± 5 °C)~~ onto a smooth concrete surface. ~~Each sample~~ **The TPRD** is allowed to bounce on the concrete surface after the initial impact.

Up to six separate units may be used such that all six of the major axes are covered (i.e. one direction drop per sample, covering the opposing directions of 3 orthogonal axes: vertical, lateral and longitudinal). At the manufacturer's discretion, one unit may be dropped in all six orientations.

After each drop, the sample shall be examined for visible damage. Any of the six dropped orientations that do not have exterior damage that indicates that the part is unsuitable for use (i.e. threads damaged sufficiently that part is rendered unusable), shall proceed to step (b).

Note: any samples with damage from the drop that results in the TPRD not being able to be installed (i.e. thread damage) shall not proceed to step (b) and shall not be considered a failure of this test;

~~One unit is dropped in six orientations (opposing directions of 3 orthogonal axes: vertical, lateral and longitudinal). If each of the six dropped samples does not show visible exterior damage that indicates that the part is unsuitable for use, it shall proceed to step (b) ;~~

(b) Each of the~~ six~~ TPRD units dropped in step (a) **that did not have visible damage** and one additional unit not subjected to a drop are mounted in a test fixture in accordance with manufacturer's installation instructions and vibrated 30 minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequency for each axis. The most severe resonant frequencies are determined using an acceleration of 1.5 g and sweeping through a sinusoidal frequency range of 10 to 500 Hz ~~within~~ **in** 10 minutes. The resonance frequency is identified by a pronounced increase in vibration amplitude. If the resonance frequency is not found in this range, the test shall be conducted at 40 Hz. Following this test, each sample ~~shall not show visible exterior damage that indicates that the part is unsuitable for use. It~~ shall subsequently comply with the requirements of ~~Leak~~ **the leak** test (Annex 4, paragraph 1.8.), **bench top activation test (Annex 4, paragraph 1.9.) and flow** ~~Flow~~ rate test (Annex 4, paragraph 1.10.) ~~and Bench top activation test (Annex 4, paragraph 1.9.)~~.

1.8. Leak test

~~A~~ **This test applies to one** TPRD that has not undergone previous **design qualification tests and additional units as specified in other tests in Annex 4, paragraph 1. The leak test is performed at ambient, high and low temperatures. The unit shall be thermally conditioned at each of the required test temperatures and held pressurized to ≥2 MPa for at least one hour to ensure thermal stability before testing. The TRPD is pressurized with leak test gas at the inlet.** ~~testing is tested at ambient, high and low temperatures without being subjected to other design qualification tests. The unit is held for one hour at each temperature and test pressure before testing.~~ The ~~three temperature~~ test conditions are:

(a) Ambient temperature: condition the unit at **ambient temperature** ~~20 (±5) °C~~; test at **2 ± 0.5 MPa** ~~5 per cent NWP (+0/-2 MPa)~~ and ≥ **125**~~150~~ per cent NWP ~~(+2/-0 MPa)~~;

(b) High temperature: condition the unit at ≥ 85 °C ~~or higher~~; test at **2 ± 0.5 MPa** ~~5 per cent NWP (+0/-2 MPa)~~ and **≥ 125**~~150~~ per cent NWP ~~(+2/-0 MPa)~~;

(c) Low temperature: condition the unit at ≤ -40 °C ~~or lower~~; test at **2 ± 0.5 MPa** ~~5 per cent NWP (+0/-2 MPa)~~ and ≥ 100 per cent NWP ~~(+2/-0 MPa)~~.

~~Additional units undergo leak testing as specified in other tests in Annex 4, paragraph 1. with uninterrupted exposure at the temperature specified in those tests.~~

~~At all specified test temperatures, the unit is conditioned for one minute by immersion in a temperature controlled fluid (or equivalent method). If no bubbles are observed for the specified time period, the sample passes the test. If bubbles are detected, the leak rate is measured by an appropriate method.~~ **Following conditioning at each of the specified test temperatures, the unit is observed for leakage while immersed in a temperature-controlled fluid (or equivalent method) for at least one minute at each of the test pressures listed above. If no bubbles are observed for the specified time period, the sample passes the test. If bubbles are detected, the leak rate is measured.** The total hydrogen leak rate shall be less than 10 **Nml/h.** ~~Nml/hr.~~

1.9. Bench top activation test

Three ~~Two~~ new TPRD units are tested without being subjected to other design qualification tests in order to establish a baseline time for activation**, which is defined as the averaged activation time of these three units**. Additional pre-tested units (pre-tested according to Annex 4, paragraphs 1.1., 1.3., 1.4., 1.5. **and** ~~or~~ 1.7.) undergo bench top activation testing as specified in other tests in Annex 4, paragraph 1.

(a) The test setup consists of either an oven or chimney which is capable of controlling air temperature and flow to achieve 600 ± **10** ~~(±10)~~ °C in the air surrounding the TPRD. The TPRD unit is not exposed directly to flame. The TPRD unit is mounted in a fixture according to the manufacturer's installation instructions; the test configuration is to be documented;

(b) A thermocouple is placed in the oven or chimney to monitor the temperature. The temperature **shall remain** ~~remains~~ within the acceptable range for **at least** two minutes prior to running the test;

(c) **Prior to insertion, the TPRD unit is pressurized to 2 ± 0.5 MPa;** ~~The pressurized TPRD unit is inserted into the oven or chimney, and the time for the device to activate is recorded. Prior to insertion into the oven or chimney, one new (not pre-tested) TPRD unit is pressurized to no more than 25 per cent NWP (the pre-tested); TPRD units are pressurized to no more than 25 per cent NWP; and one new (not pre-tested) TPRD unit is pressurized to 100 per cent NWP~~;

(d) **The pressurized TPRD unit is inserted into the oven or chimney, and the time for the device to activate is recorded;**

(**e**~~d~~) TPRD units previously subjected to other tests in Annex 4, paragraph 1. shall activate within a period no more than two minutes longer than the baseline activation time ~~of the new TPRD unit that was pressurized to up to 25 per cent NWP~~;

(**f**~~e~~) The **maximum** difference in the activation time of the **three** ~~two~~ TPRD units that had not undergone previous testing shall be no more than **two** ~~2~~ minutes.

1.10. Flow rate test

(a) Eight TPRD units are tested for flow capacity. The eight units consist of three new TPRD units and one TPRD unit from each of the following previous tests: Annex 4, paragraphs 1.1., 1.3., 1.4., 1.5. and 1.7.;

(b) Each TPRD unit is activated according to Annex 4, paragraph 1.9. After activation and without cleaning, removal of parts, or reconditioning, each TPRD unit is subjected to **a** flow test ~~using hydrogen, air or an inert gas~~;

(c) Flow rate testing is conducted with ~~a gas~~ **an** inlet pressure of 2 ± **0.5** ~~(±0.5)~~ MPa. The outlet is at ambient pressure. The inlet ~~temperature and~~ pressure **and flow rate** are recorded;

(d) Flow rate is measured with accuracy within ±2 per cent. The lowest measured value of the eight pressure relief devices shall not be less than 90 per cent of the highest flow value.

1.11. Atmospheric exposure test

The atmospheric exposure test applies to qualification of TPRDs if the component has non-metallic materials exposed to the atmosphere during normal operating conditions.

(a) All non-metallic materials that provide a fuel containing seal, and that are exposed to the atmosphere, for which a satisfactory declaration of properties is not submitted by the applicant, shall not crack or show visible evidence of deterioration after exposure to oxygen for at least 96 hours at 70 °C and 2 MPa in accordance with ISO 188:2011 or ASTM D572-04(2019);

(b) **All elastomers that are exposed to the atmosphere shall demonstrate resistance to ozone by one or more of the following:**

(i) **Specification of elastomer compounds with established resistance to ozone;**

(ii) **Component testing in accordance with ISO 1431-1:2012, ASTM D1149-18, or equivalent test methods;**

(iii) **The test piece shall be stressed to 20 per cent elongation, exposed to air at 40 °C with an ozone concentration of 50 parts per hundred million for 120 hours. The non-metallic materials in the test piece shall not crack or show visible evidence of deterioration after exposure to ozone.**

2. Tests for check valve and shut-off valve

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests are performed at ambient temperature 20 (±5) °C unless otherwise specified. The check valve and shut-off valve qualification performance tests are specified as follows (see also Appendix 2):

2.1. Hydrostatic strength test

The outlet opening in components is plugged and valve seats or internal blocks are made to assume the open position. One unit is tested without being subjected to other design qualification tests in order to establish a baseline burst pressure., o**O**ther units are tested as specified in subsequent tests of Annex 4, paragraph 2.

(a) A hydrostatic pressure of ≥ 250 per cent NWP (+2/-0 MPa) is applied to the inlet of the component for **at least** three minutes. The component is examined to ensure that rupture has not occurred;

(b) The hydrostatic pressure is then increased at a rate of less than or equal to ≤ 1.4 MPa/sec until component failure. The hydrostatic pressure at failure is recorded. The failure pressure of previously tested units shall be no less than≥ 80 per cent of the failure pressure of the baseline, unless the hydrostatic pressure exceeds 400 per cent NWP.

2.2. Leak test

This test applies to one unit that has not undergone previous design qualification tests and additional units as specified in other tests in Annex4, paragraph 2. The leak test is performed at ambient, high and low temperatures. The unit shall be thermally conditioned at each of the required test temperatures and held pressurized to ≥ 2 MPa for at least one hour to ensure thermal stability before testing. The outlet opening is plugged with the appropriate mating connection and pressurized leak test gas is applied to the inlet. The required test conditions are:

One unit that has not undergone previous testing is tested at ambient, high and low temperatures without being subjected to other design qualification tests. The three temperature test conditions are:

(a) Ambient temperature: condition the unit at 20 ± **5** (±5) °C; test at **2 ± 0.5 MPa** 5 per cent NWP (+0/-2 MPa) and ≥ **125** 150 per cent NWP (+2/-0 MPa) ;

(b) High temperature: condition the unit at ≥ 85 °C~~ or higher ~~; test at **2 ± 0.5 MPa** ~~5 per cent NWP (+0/-2 MPa)~~ and ≥ **125**~~ 150~~ per cent NWP ~~(+2/-0 MPa)~~ ;

(c) Low temperature: condition the unit at ≤ -40 °C~~ or lower~~; test at **2 ± 0.5 MPa** ~~5 per cent NWP (+0/-2 MPa)~~ and ≥ 100 per cent NWP~~ (+2/-0 MPa)~~.

~~Additional units undergo leak testing as specified in other tests in Annex 4, paragraph 2. with uninterrupted exposure at the temperatures specified in those tests.~~

~~The outlet opening is plugged with the appropriate mating connection and pressurized hydrogen is applied to the inlet. At all specified test temperatures, the unit is conditioned for one minute by immersion in a temperature controlled fluid (or equivalent method).~~ **Following conditioning at each of the specified test temperatures, the unit is observed for leakage while immersed in a temperature-controlled fluid (or equivalent method) for at least one minute at each of the test pressures listed above.** If no bubbles are observed for the specified time period, the sample passes the test. If bubbles are detected, the leak rate is measured by an appropriate method. The leak rate shall not exceed 10 Nml/h ~~Nml/hr~~ of hydrogen gas.

2.3. Extreme temperature pressure cycling test

The total number of operational cycles is 15,000 for the check valve and 50,000 for the shut-off valve. The valve unit is installed in a test fixture corresponding to the manufacturer's specifications for installation.

(a) The operation of the unit is continuously repeated using hydrogen or non-reactive gas at all specified temperatures and pressures as follows:

(i) Ambient temperature cycling. The unit undergoes 90 per cent of the total operational cycles at ≥ 100 per cent NWP with the part stabilized at ambient temperature;

(ii) High temperature cycling. The unit then undergoes 5 per cent of the total operational cycles at ≥125 per cent NWP with the part stabilized at ≥85°C;

(iii) Low temperature cycling. The unit then undergoes 5 per cent of the total operational cycles at ≥ 80 per cent NWP with the part stabilized at ≤ -40°C.

(b) The operational cycle requirements shall be as follows:

(i) Check Valve: A check valve shall be capable of withstanding 15,000 cycles of operation, and at least 24 hours of chatter flow when submitted to the following test procedure. The check valve shall be connected to a test fixture. The required test pressure is applied in six pulses to the inlet of the check valve with the outlet closed. The pressure shall then be vented from the check valve inlet. Failure of the check valve to reseat and prevent backflow shall constitute failure of the check valve. The pressure shall then be lowered on the check valve outlet side to ≤ 60 per cent of NWP prior to the next cycle.Following the operation cycles, the check valve shall be subjected to at least 24 hours of chatter flow at a flow rate

that causes the most chatter (valve flutter). At the completion of the test, the check valve shall comply with the leak test (Annex 4, paragraph 2.2.) and hydrostatic strength test (Annex 4, paragraph 2.1.);

(ii) Shut-off valve: A shut-off valve shall be capable of withstanding 50,000 cycles of operation when submitted to the following test procedure. The shut-off valve shall be mounted into a suitable test fixture. Each cycle shall consist of filling through the inlet port to the required test pressure. The shut-off valve shall then be opened (energized) and the pressure in the valve/fixture reduced to 50 percent of the filling test pressure. The shut-off valve shall then be closed (de-energized) prior to the next filling cycle.

Following the operation cycles, the shut-off valve shall be subjected to at least 24 hours of chatter flow at a flow rate that is within normal operating conditions that causes chatter (valve flutter), only if the shut-off valve is functioning as a check valve during fuelling.

Note: If no chatter is induced during normal flow rates, this 24 h chatter flow test is not required.

At the completion of the test the shut-off valve shall comply with the leak test Annex 4, paragraph 2.2.) and hydrostatic strength test Annex 4, paragraph 2.1.).

~~(a) The total number of operational cycles is 11,000 for a 15-year service life or 15,000 operational cycles for a 20-year service life for the check valve and 50,000 for a 15-year service life or 67,000 operational cycles for a 20-year service life for the shut-off valve. The valve unit are installed in a test fixture corresponding to the manufacturer's specifications for installation. The operation of the unit is continuously repeated using hydrogen gas at all specified pressures.~~

~~An operational cycle shall be defined as follows:~~

~~(i) A check valve is connected to a test fixture and 100 per cent NWP (+2/-0 MPa) is applied in six step pulses to the check valve inlet with the outlet closed. The pressure is then vented from the check valve inlet. The pressure is lowered on the check valve outlet side to less than 60 per cent NWP prior to the next cycle;~~

~~(ii) A shut-off valve is connected to a test fixture and pressure is applied continuously to the both the inlet and outlet sides.~~

~~An operational cycle consists of one full operation and reset.~~

~~(b) Testing is performed on a unit stabilized at the following temperatures:~~

~~(i) Ambient temperature cycling. The unit undergoes operational (open/closed) cycles at 125 per cent NWP (+2/-0 MPa) through 90 per cent of the total cycles with the part stabilized at 20 (±5) °C. At the completion of the ambient temperature operational cycles, the unit shall comply with the ambient temperature leak test specified in Annex 4, paragraph 2.2.;~~

~~(ii) High temperature cycling. The unit then undergoes operational cycles at 125 per cent NWP (+2/-0 MPa) through 5 per cent of~~

~~the total operational cycles with the part stabilized at 85 °C or higher. At the completion of the 85 °C cycles, the unit shall comply with the high temperature (85 °C) leak test specified in Annex 4, paragraph 2.2.;~~

~~(iii) Low temperature cycling. The unit then undergoes operational cycles at 100 per cent NWP (+2/-0 MPa) through 5 per cent of the total cycles with the part stabilized at -40 °C or lower. At the completion of the -40 °C operational cycles, the unit shall comply with the low temperature (-40 °C) leak test specified in Annex 4, paragraph 2.2.~~

~~(c) Check valve chatter flow test: Following 11,000 operational cycles for a 15-year service life or 15,000 operational cycles for a 20-year service life and leak tests in Annex 4, paragraph 2.3.(b), the check valve is subjected to 24 hours of chatter flow at a flow rate that causes the most chatter (valve flutter). At the completion of the test the check valve shall comply with the ambient temperature leak test (Annex 4, paragraph 2.2.) and the strength test (Annex 4, paragraph 2.1.).~~

2.4. Salt corrosion resistance test

Accelerated cyclic corrosion shall be performed in accordance with the following procedure:

(a) Three component samples shall be exposed to an accelerated laboratory corrosion test, under a combination of cyclic conditions (salt solution, various temperatures, humidity, and ambient environment). The test method is comprised of 1 per cent (approximate) complex salt mist applications coupled with high temperature, high humidity and high temperature dry off. One test cycle is equal to 24 hours, as illustrated in Table 3.

Table 3
Accelerated Cyclic Corrosion Conditions (1 cycle = 24 h)

Cycle Condition	*Temperature (°C)*	*Relative Humidity (%)*	*Cycle Duration)*
Ambient stage	**25 ± 3**	**45 ± 10**	**8 h ± 10 min**
Transition 1 h ± 5 min			
Humid stage	**49 ± 2**	**100 +0/-20**	**7 h ± 10 min**
Transition 3 h ± 10 min			
Dry stage	**60 ± 2**	**≤ 30**	**5 h ± 10 min**

(b) The apparatus used for this test shall consist of a fog/environmental chamber, suitable water supply conforming to ASTM D1193-06(2018) Type IV, provisions for heating the chamber, and the necessary means of controlling temperature between 22 °C and 62 °C. The apparatus shall include provisions for a supply of suitably conditioned compressed air and one or more nozzles for fog generation. The nozzle or nozzles used for the generation of the fog shall be directed or baffled to minimize any direct impingement on the test samples.

(c) **The apparatus shall consist of the chamber design as defined in ISO 6270-2:2017. During "wet-bottom" generated humidity cycles, the testing agency must confirm that visible water droplets are found on the samples to verify proper wetness.**

(d) **Steam generated humidity may be used provided the source of water used in generating the steam is free of corrosion inhibitors. During steam generated humidity cycles, the proper wetness shall be confirmed by visual inspection of visible water droplets on the samples.**

(e) **The apparatus for the dry off stage shall have the ability to obtain and maintain the following environmental conditions: temperature: 60 ± 2 °C and humidity: ≤ 30 percent RH. The apparatus shall also have sufficient air circulation to prevent temperature stratification, and also allow thorough drying of the test samples.**

(f) **The force/impingement from this salt application shall not remove corrosion or damage the coatings/paints system of test samples.**

(g) **The complex salt solution in percent by mass shall be as specified below:**

(i) **Sodium Chloride ($NaCl$): 0.9 per cent;**

(ii) **Calcium Chloride ($CaCl_2$): 0.1 per cent;**

(iii) **Sodium Bicarbonate ($NaHCO_3$): 0.075 per cent;**

Sodium Chloride must be reagent grade or food grade. Calcium Chloride must be reagent grade. Sodium Bicarbonate must be reagent or food grade (e.g., Baking Soda or comparable product is acceptable). Water must meet ASTM D1193-06(2018) Type IV requirements.

NOTE: Either $CaCl_2$ or $NaHCO_3$ material must be dissolved separately in water and added to the solution of the other materials. If all solid materials are added dry, an insoluble precipitate may result.

(h) **The component samples shall be installed in accordance with the manufacturer's recommended procedure and exposed to the cyclic corrosion test method described in Table 3.**

(i) **Repeat the cycle daily until 100 cycles of exposure have been completed. For each salt mist application, the solution shall be sprayed as an atomized mist, using the spray apparatus to mist the components until all areas are thoroughly wet / dripping. Suitable application techniques include using a plastic bottle, or a siphon spray powered by oil-free regulated air to spray the test samples. The quantity of spray applied shall be sufficient to visibly rinse away salt accumulation left from previous sprays. A total of four salt mist applications shall be applied during the ambient stage. Salt mist is not applied during any other stage of the test. The first salt mist application occurs at the beginning of the ambient stage. Each subsequent salt mist application shall be applied approximately ninety minutes after the previous application in order to allow adequate time for test sample to dry. If the test must** be interrupted for weekends and holidays, the test article shall be kept at the ambient temperature of 25 ± 3 °C °and the relative humidity of 45 ± 10 per cent and the cycle shall restart from ambient stage.**

(j) **Humidity ramp times between the ambient and wet condition, and between the wet and dry conditions, can have a significant effect on test acceleration (this is because corrosion rates are highest during these transition periods). The time from ambient to the wet condition shall be 60 ± 5 minutes and the transition time between wet and dry conditions shall be 180 ± 5 minutes.**

~~The component is supported in its normally installed position and exposed for 500 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus). The temperature within the fog chamber is maintained at 30 — 35 °C). The saline solution consists of 5 per cent sodium chloride and 95 per cent distilled water, by weight.~~

(k) Immediately after the corrosion test, the sample is rinsed **with fresh tap water** and **allowed to dry before evaluating.**

(l) The tested samples shall then be subjected to the leak test (Annex 4, paragraph 2.2.) and hydrostatic strength test (Annex 4, paragraph 2.1.)

~~and gently cleaned of salt deposits, examined for distortion, and then shall comply with the requirements of:~~

~~(a) The component shall not show signs of physical degradation that could impair the function of the component, specifically: cracking, softening or swelling. Cosmetic changes such as pitting or staining are not failures;~~

~~(b) The ambient temperature leak test (Annex 4, paragraph 2.2.);~~

~~(c) The hydrostatic strength test (Annex 4, paragraph 2.1.).~~

2.5. Vehicle environment test

Resistance to degradation by exposure to automotive fluids is determined by the following test.

(a) The inlet and outlet connections of the valve unit are connected or capped in accordance with the manufacturers installation instructions. The external surfaces of the valve unit are exposed for **at least** 24 hours at **ambient temperature** ~~20 (±5) °C~~ to each of the following fluids:

(i) Sulphuric acid -19 per cent solution by volume in water;

(ii) ~~Sodium hydroxide -25 per cent solution by weight in water;~~ **Ethanol/gasoline – 10 per cent/90 per cent concentration of E10 fuel; and**

(iii) ~~Ammonium nitrate -28 per cent by weight in water; and~~

~~(iv)~~ Windshield washer fluid (50 per cent by volume methyl alcohol and water).

The fluids are replenished as needed to ensure complete exposure for the duration of the test. A distinct test is performed with each of the fluids. One component may be used for exposure to all of the fluids in sequence.

(b) After exposure to each chemical, the component is wiped off and rinsed with water;

(c) The component shall not show signs of physical degradation that could impair the function of the component, specifically: cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not failures. At the conclusion of all exposures, the unit(s) shall comply with the requirements of ~~the ambient temperature leakage~~ the **leak** test (Annex 4, paragraph 2.2.) and ~~Hydrostatic Strength Test~~ **hydrostatic strength test** (Annex 4, paragraph 2.1.).

2.6. Atmospheric exposure test

The atmospheric exposure test applies to qualification of check valve and ~~automatic~~ shut-off valves if the component has non-metallic materials exposed to the atmosphere during normal operating conditions.

(a) All non-metallic materials that provide a fuel containing seal, and that are exposed to the atmosphere, for which a satisfactory declaration of properties is not submitted by the applicant, shall not crack or show visible evidence of deterioration after exposure to oxygen for **at least** 96 hours at 70 °C ~~at~~ **and** 2 MPa in accordance with **ISO 188:2011 or** ASTM D572**-04 (2019)** ~~(Standard Test Method for Rubber Deterioration by Heat and Oxygen)~~;

(b) All elastomers shall demonstrate resistance to ozone by one or more of the following:

(i) Specification of elastomer compounds with established resistance to ozone;

(ii) Component testing in accordance with **ISO 1431-1:2012, ASTM D1149-1** ~~ISO 1431/1, ASTM D1149~~, or equivalent test methods**;**

(iii) The test piece, shall be stressed to 20 per cent elongation, exposed to air at 40 °C with an ozone concentration of 50 parts per hundred million during 120 h. The non-metallic materials in the test piece shall not crack or show visible evidence of deterioration after exposure to ozone.

2.7. Electrical Tests

The electrical tests apply to qualification of the ~~automatic~~ shut-off valve; they do not apply to qualification of check valves.

(a) Abnormal voltage test. The solenoid valve is connected to a variable DC voltage source. The solenoid valve is operated as follows:

(i) An equilibrium (steady state temperature) hold is established for **at least** one hour at ≥ 1.5 times the rated voltage;

(ii) The voltage is increased to ≥ **2** ~~two~~ times the rated voltage or 60 volts, whichever is less, and held for **at least** one minute;

(iii) Any failure shall not result in external **valve** leakage **in accordance with Annex 4, paragraph 2.2.**, open valve or **other** unsafe conditions such as smoke, fire or melting.

~~The minimum opening voltage at NWP and room temperature shall be less than or equal to 9 V for a 12 V system and less than or equal to 18 V for a 24 V system.~~

(b) Insulation resistance test. 1,000 V D.C. is applied between the power conductor and the component casing for at least two seconds. The minimum allowable resistance for that component is 240 kΩ.

2.8. Vibration test

The valve unit is pressurized to ~~its~~ ≥ 100 per cent NWP ~~(+2/-0 MPa) with hydrogen,~~ sealed at both ends, and vibrated for 30 minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequencies. The most severe resonant frequencies are determined by acceleration of 1.5 g with a sweep time of **at least** 10 minutes within a sinusoidal frequency range of 10 to **500** ~~40~~ Hz. If the resonance frequency is not found in this range the test is conducted at 40Hz. Following this test, each sample shall not show visible exterior damage that indicates that the performance of the part is compromised. At the completion of the test, the unit shall comply with the requirements of the ~~ambient temperature~~ leak test specified in Annex 4, paragraph 2.2. **and hydrostatic strength test specified in Annex 4, paragraph 2.1.**

2.9. Stress corrosion cracking test

This test is applicable to valve units containing copper alloys exposed to the outside environment.

For the valve units containing components made of a copper~~-based~~ alloy (e.g. brass), one valve unit is tested. The valve unit is disassembled, all copper~~-based~~ alloy components are degreased and then the valve unit is reassembled before it is continuously exposed for **at least 10** ~~ten~~ days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover.

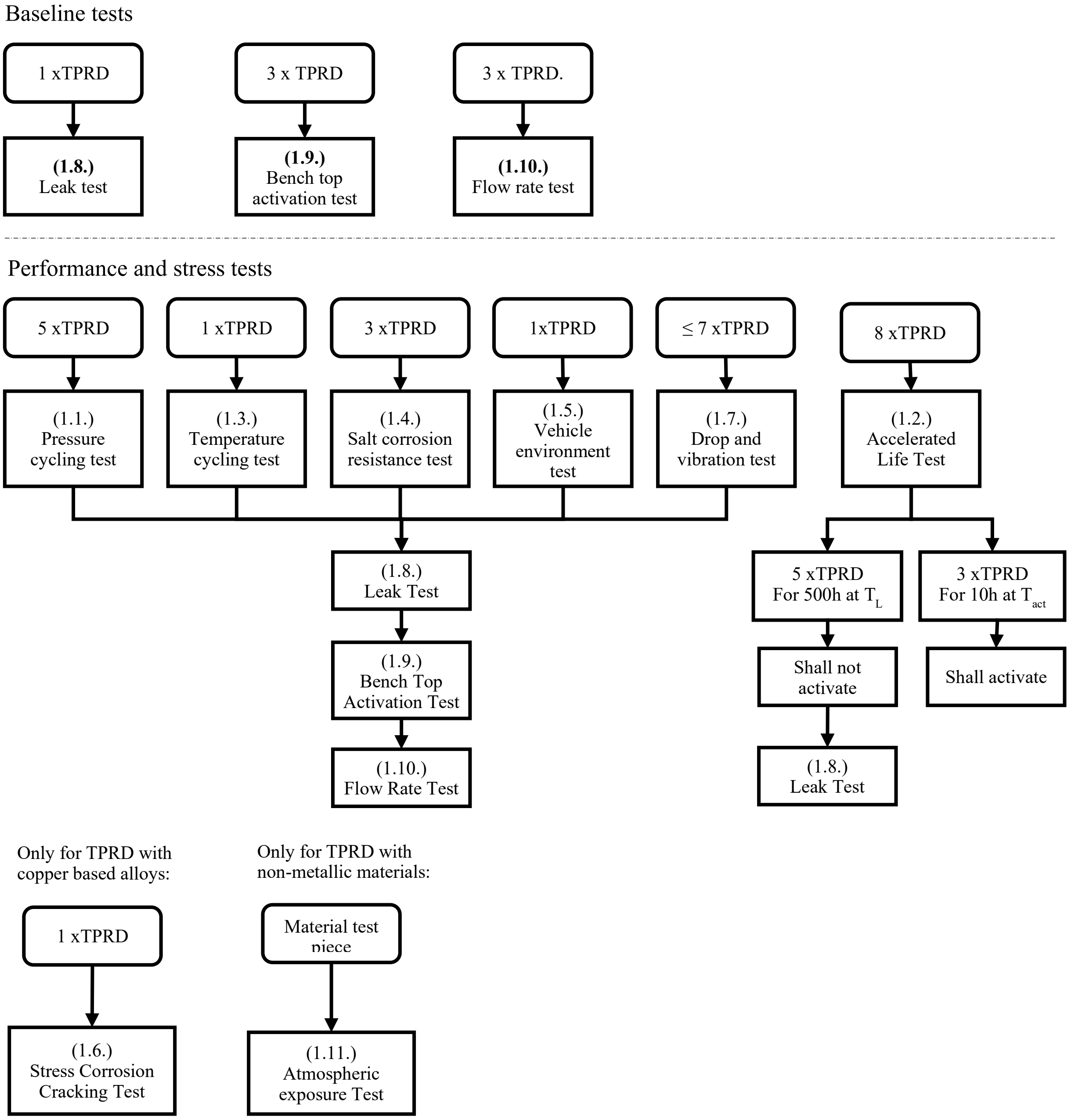
Aqueous ammonia having a specific gravity of 0.94 is maintained at the bottom of the glass chamber below the sample at a concentration of at least 20 ml per litre of chamber volume. The sample is positioned 35 ± **5** ~~(±5)~~ mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture is maintained at atmospheric pressure at 35 ± **5** ~~(±5)~~ ºC. Copper-~~based~~ alloy components shall not exhibit cracking or delaminating due to this test.

~~2.10. Pre-cooled hydrogen exposure test~~

~~The valve unit is subjected to pre-cooled hydrogen gas at -40 ºC or lower at a flow rate of 30 g/sec at external temperature of 20 (±5) ºC for a minimum of three minutes. The unit is de-pressurized and re-pressurized after a two minute hold period. This test is repeated ten times. This test procedure is then repeated for an additional ten cycles, except that the hold period is increased to 15 minutes. The unit shall then comply with the requirements of the ambient temperature leak test specified in Annex 4, paragraph 2.2.~~

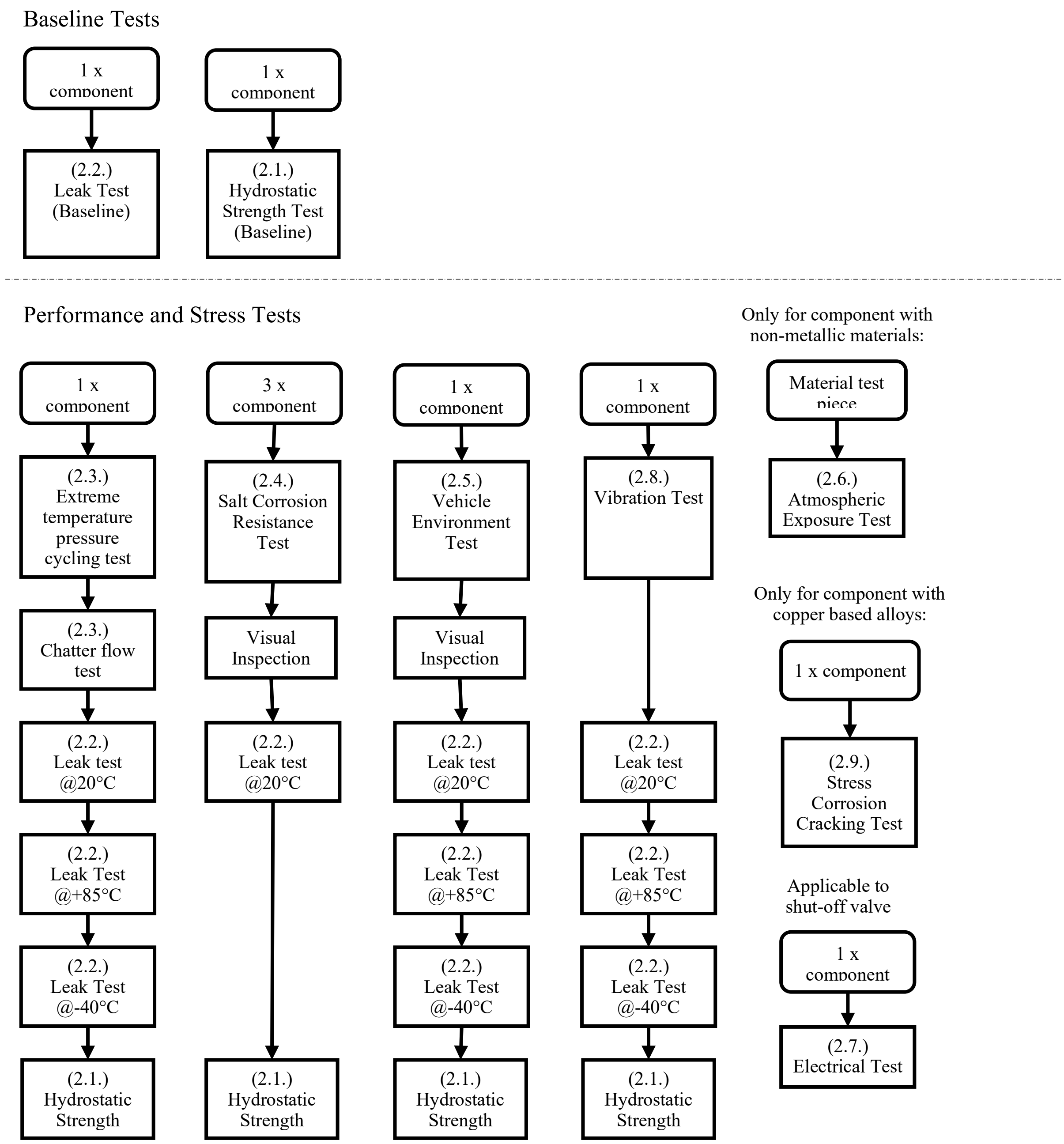
Annex 4 - Appendix 1

Overview of TPRD tests



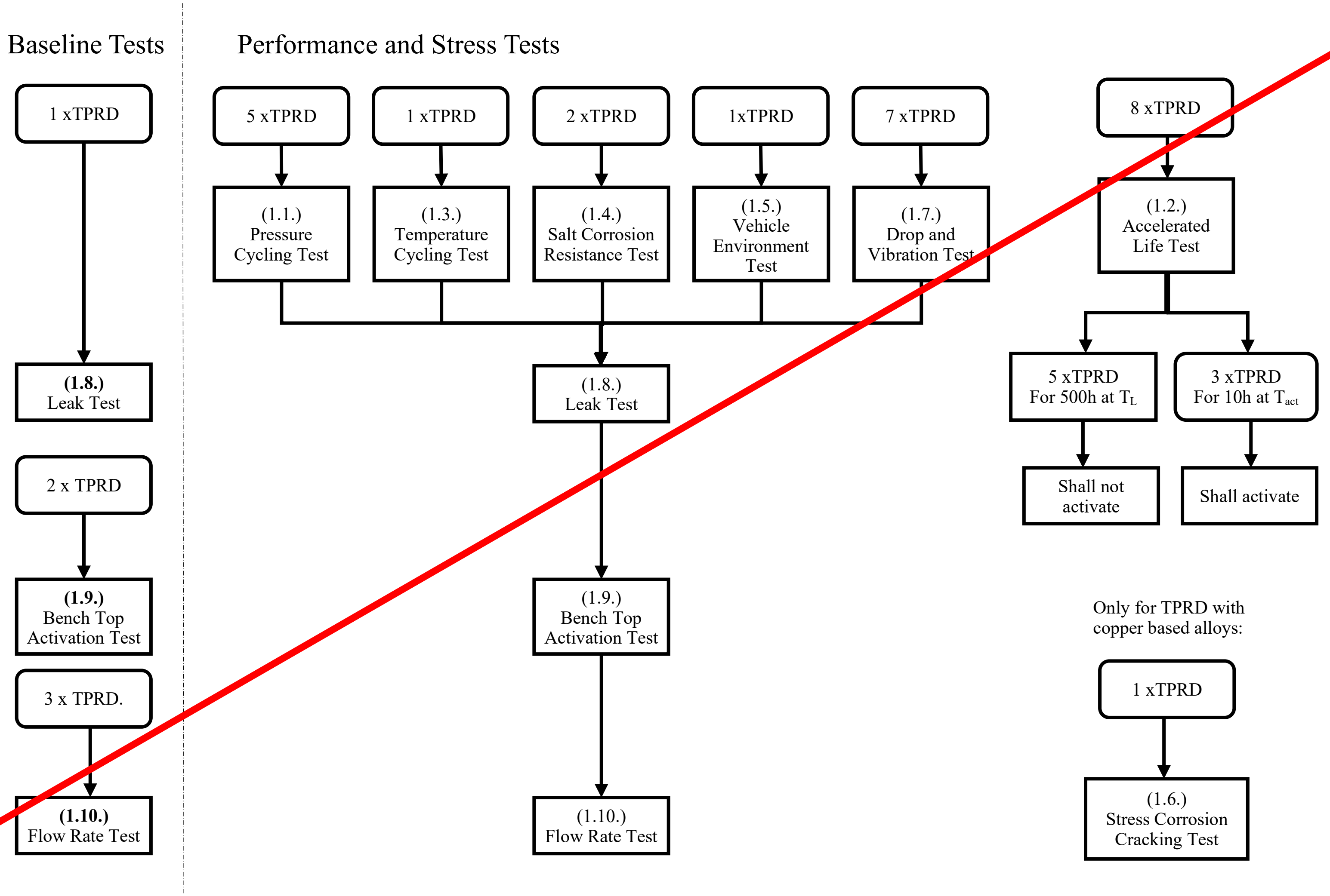
Annex 4 - Appendix 2

Overview of check valve and automatic shut-off valve tests



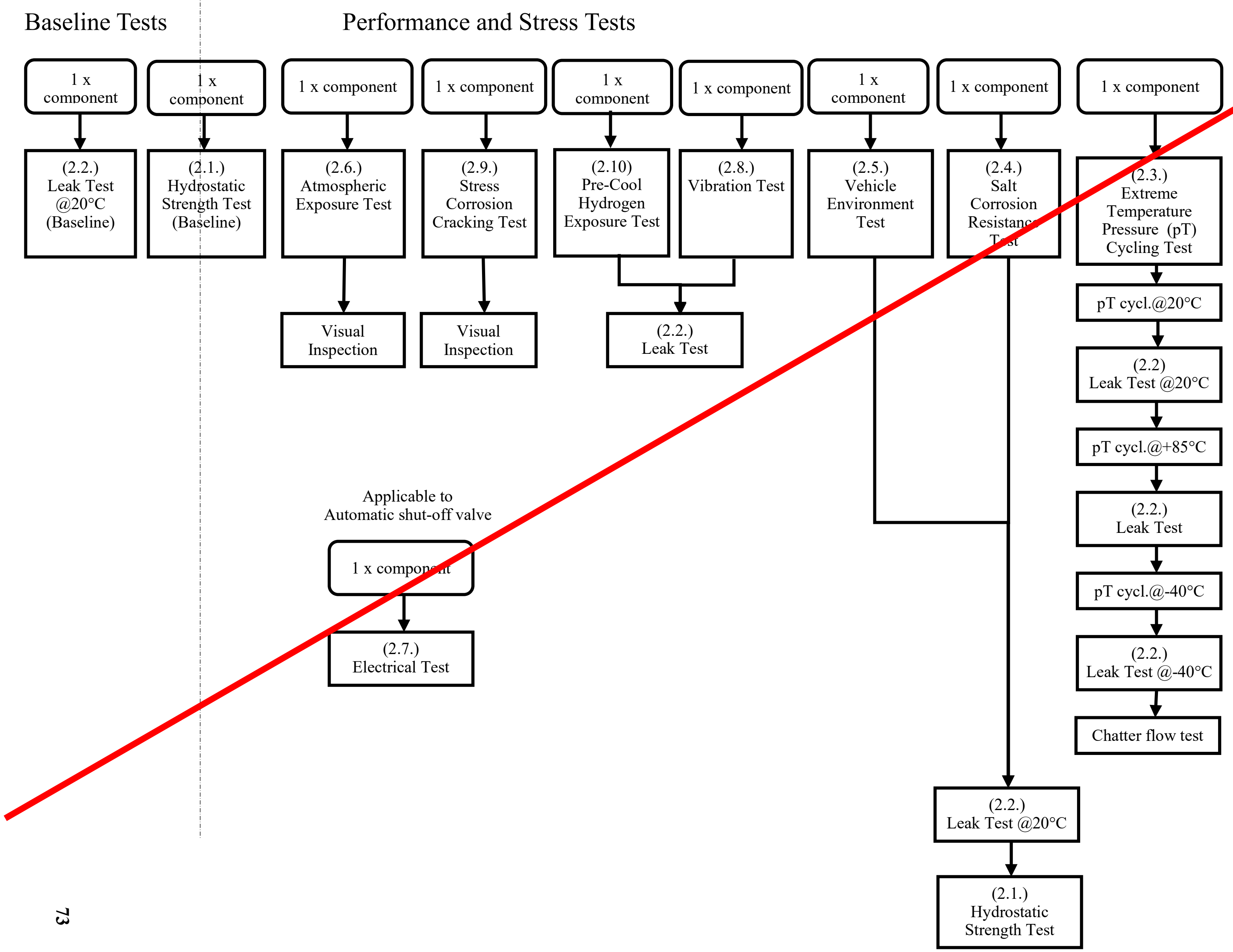
Annex 4 - Appendix 1

Overview of TPRD tests



Annex 4 - Appendix 2

Overview of check valve and automatic shut-off valve tests



"

Annex 5, paragraphs 1. to 3., amend to read:

"1. Post-crash compressed hydrogen storage system leak test

The crash tests used to evaluate post-crash hydrogen leakage are those set out in paragraph 7.2. of this Regulation.

Prior to conducting the crash test, instrumentation is installed in the **CHSS** ~~hydrogen storage system~~ to perform the required pressure and temperature measurements if the standard vehicle does not already have instrumentation with the required accuracy.

The **CHSS** ~~storage system~~ is then purged, if necessary, following manufacturer's directions to remove impurities from the container before filling the **CHSS** ~~storage system~~ with compressed hydrogen or helium gas. Since the storage system pressure varies with temperature, the targeted fill pressure is a function of the temperature. The target pressure shall be determined from the following equation:

$P_{target} = NWP \times (273 + T_o) / 288$

where NWP is the Nominal Working Pressure (MPa), T_o is the ambient temperature to which the storage system is expected to settle, and P_{target} is the targeted fill pressure after the temperature settles.

The container is filled to a minimum of 95 per cent of the targeted fill pressure and allowed to settle (stabilize) prior to conducting the crash test.

The main stop valve and shut-off valves for hydrogen gas, located in the downstream hydrogen gas piping, are in **the** normal driving condition **kept open** immediately prior to the impact.

1.1. Post-crash leak test: compressed hydrogen storage system filled with compressed hydrogen

The hydrogen gas pressure, P_0 (MPa) and temperature, T_0 (°C) are measured immediately before the impact and then at a time interval, Δt (min), after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. The time interval, Δt, shall be increased, if necessary, to accommodate measurement accuracy for a storage system with a large volume operating up to 70MPa; in that case, Δt is calculated from the following equation:

$\Delta t = V_{CHSS} \times NWP /1{,}000 \times ((-0.027 \times NWP +4) \times R_s - 0.21) -1.7 \times R_s$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the **CHSS** ~~compressed hydrogen storage system~~ (L), and Δt is the time interval (min). If the calculated value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the **CHSS** ~~storage system~~ is calculated as follows:

$P_o' = P_o \times 288 / (273 + T_0)$

$\rho_o' = -0.0027 \times (P_0')^2 + 0.75 \times P_0' +$ ~~0.5789~~**1.07**

$M_o = \rho_o' \times V_{CHSS}$

The final mass of hydrogen in the **CHSS** ~~storage system~~, M_f, at the end of the time interval, Δt, is calculated as follows:

$P_f' = P_f \times 288 / (273 + T_f)$

$\rho_f' = -0.0027 \times (P_f')^2 + 0.75 \times P_f' +$ ~~0.5789~~**1.07**

$M_f = \rho_f' \times V_{CHSS}$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average hydrogen flow rate over the time interval (that shall be less than the criteria in paragraph 7.2.1.) is therefore

$V_{H2} = (M_f - M_o) / \Delta t \times 22.41 / 2.016 \times (P_{target} / P_o)$

where V_{H2} is the average volumetric flow rate (NL/min) over the time interval and the term (P_{target} /P_o) is used to compensate for differences between the measured initial pressure, P_o, and the targeted fill pressure P_{target}.

1.2. Post-crash leak test: ~~C~~compressed hydrogen storage system filled with compressed helium

The helium gas pressure, P_0 (MPa), and temperature T_0 (°C), are measured immediately before the impact and then at a predetermined time interval after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. The time interval, Δt, shall be increased if necessary in order to accommodate measurement accuracy for a **CHSS** ~~storage system~~ with a large volume operating up to 70MPa; in that case, Δt is calculated from the following equation:

$\Delta t = V_{CHSS} \times NWP / 1{,}000 \times ((-0.028 \times NWP + 5.5) \times R_s - 0.3) - 2.6 \times R_s$

where $R_s = P_s$ / NWP, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the **CHSS** ~~compressed storage system~~ (L), and Δt is the time interval (min). If the value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of helium in the **CHSS** ~~storage system~~ is calculated as follows:

$P_o' = P_o \times 288 / (273 + T_0)$

$\rho_o' = -0.0043 \times (P_0')^2 + 1.53 \times P_0' + 1.49$

$M_o = \rho_o' \times V_{CHSS}$

The final mass of helium in the ~~storage system~~ **CHSS**, M_f, at the end of the time interval, Δt, is calculated as follows:

$P_f' = P_f \times 288 / (273 + T_f)$

$\rho_f' = -0.0043 \times (P_f')^2 + 1.53 \times P_f' + 1.49$

$M_f = \rho_f' \times V_{CHSS}$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average helium flow rate over the time interval is therefore

$V_{He} = (M_f - M_o) / \Delta t \times 22.41 / 4.003 \times (P_{target} / P_o)$

where V_{He} is the average volumetric flow rate (NL/min) over the time interval and the term P_{target}/ P_o is used to compensate for differences between the measured initial pressure (P_o) and the targeted fill pressure (P_{target}).

Conversion of the average volumetric flow of helium to the average hydrogen flow is calculated with the following expression:

$V_{H2} = V_{He} / 0.75$

where V_{H2} is the corresponding average volumetric flow of hydrogen (that shall be less than the requirements in paragraph 7.2.1. of this Regulation to comply with).

2. Post-crash concentration test for enclosed spaces

The measurements are recorded in the crash test that evaluates potential hydrogen (or helium) leakage (Annex 5, paragraph 1. test procedure).

Sensors are selected to measure either the build-up of the hydrogen or helium gas or the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

Sensors are calibrated to traceable references to ensure an accuracy of ±5 per cent at the targeted criteria of 4**.0** per cent hydrogen or 3**.0** per cent helium by volume in air, and a ~~full scale~~ **full-scale** measurement capability of at least 25 per cent above the target criteria. The sensor shall be capable of a 90 per cent response to a ~~full scale~~ **full-scale** change in concentration within 10 seconds.

Prior to the crash impact, the sensors are located in the passenger **and** ~~and,~~ luggage compartments of the vehicle as follows:

(a) At a distance within 250 mm of the headliner above the driver's seat or near the top centre the passenger compartment;

(b) At a distance within 250 mm of the floor in front of the rear (or rear most) seat in the passenger compartment;

(c) At a distance within 100 mm of the top of luggage **compartment** ~~compartments~~ within the vehicle that are not directly affected by the particular crash impact to be conducted.

The sensors are securely mounted on the vehicle structure or seats and protected for the planned crash test from debris, air bag exhaust gas and projectiles. The measurements following the crash are recorded by instruments located within the vehicle or by remote transmission.

The vehicle may be located either outdoors in an area protected from the wind and possible solar effects or indoors in a space that is large enough or ventilated to prevent the build-up of hydrogen to more than 10 per cent of the targeted criteria in the passenger and luggage compartments.

Post-crash data collection in enclosed spaces commences when the vehicle comes to a rest. Data from the sensors are collected at least every 5 seconds and continue for a period of 60 minutes after the test. A first-order lag (time constant) up to a maximum of 5 seconds may be applied to the measurements to provide "smoothing" and filter the effects of spurious data points.

The filtered readings from each sensor shall be below the targeted criteria of 4.0 per cent for hydrogen or 3.0 per cent for helium at all times throughout the 60 minutes post-crash test period.

3. Compliance test for single failure conditions

For requirement of paragraph 7.1.4.2., test procedure of Annex 5, paragraph 3.2. shall be executed.

For requirement of paragraph 7.1.4.3., test procedure of Annex 5, paragraph 3.1. or paragraph 3.2. shall be executed:~~Either test procedure of Annex 5, paragraph 3.1. or paragraph 3.2. shall be executed:~~ "

Annex 5, paragraph 3.1.1.2., amend to read:

"3.1.1.2. Test gas: Two mixtures of air and hydrogen gas: **>** 3.0 per cent concentration ~~(or less)~~ of hydrogen in the air to verify function of the warning, and **>** 4.0 per cent concentration ~~(or less)~~ of hydrogen in the air to verify the shut-down function. The proper concentrations are selected based on the recommendation (or the detector specification) by the manufacturer.

NOTE: The storage of pre-mixed gases of greater than 2 per cent hydrogen in air in compressed gas cylinders may be restricted or prohibited in various jurisdictions where test laboratories are located. As an alternative, gas mixtures up to 4 per cent hydrogen in-situ within the test area by a mixing station that injects the required amount of hydrogen into a flowing streaming of air. The hydrogen/air mixture can then be delivered to the point of release within the vehicle by a flexible hose."

Annex 5, paragraph 3.1.2.2., amend to read:

"3.1.2.2. Execution of the test

(a) Test gas is blown to the hydrogen gas leakage detector;

(b) Proper function of the warning system is confirmed **within 10 seconds** when tested with the gas to verify function of the warning;

(c) The main shut-off valve is confirmed **within 10 seconds** to be closed when tested with the gas to verify function of the shut-down. For example, the monitoring of the electric power to the shut-off valve or of the sound of the shut-off valve activation may be used to confirm the operation of the main shut-off valve of the hydrogen supply. "

Annex 5, paragraph 3.2.1.3., amend to read:

"3.2.1.3. Prior to the test the vehicle is prepared to simulate remotely controllable hydrogen releases from the hydrogen system. Hydrogen releases may be demonstrated by using external fuel supply without modification of the test vehicle fuel lines. The number, location and flow capacity of the release points downstream of the main hydrogen **shut-off** ~~shutoff~~ valve are defined by the vehicle manufacturer taking worst case leakage scenarios **under a single failure condition** into account. As a minimum, the total flow of all remotely controlled releases shall be adequate to trigger demonstration of the automatic "warning" and hydrogen shut-off functions. "

[*Annex 5, paragraph 4.3.,* amend to read:

"4.3. The measuring section of the measuring device is placed ~~on~~ **along** the centre line of the exhaust gas flow within 100 mm **of where the exhaust is released to the atmosphere.** ~~from the exhaust point of discharge external to the vehicle.~~"]

[*Annex 5, paragraph 4.4.,* amend to read:

"4.4. The exhaust hydrogen concentration is continuously measured during the following steps:

(a) The power system is shut-down;

(b) Upon completion of the shut-down process, the power system is immediately started;

(c) After **completion of the start-up process as defined by the manufacturer** ~~a lapse of one minute~~, the power system is turned off and measurement continues until the power system shut-down procedure is completed. "]

[*Annex 5, paragraph 4.5.,* amend to read:

"4.5. The measurement device shall**:** ~~have a measurement response time of less than 300 milliseconds.~~

(a) Have a measurement response-time (t_0 - t_{90}) of less than 2 seconds, where t_0 is the moment of hydrogen concentration switching, and t_{90} is the time when 90% of the final indication is reached;

(b) Have a resolution time of less than 300 milliseconds (sampling rate of >3.33 Hz). "]

Annex 7, Table 1 and Notes, amend to read:

"Table 1
Change of Design

Changed Item		*Required Tests*
Metallic container or liner material		- Initial burst, Initial pressure cycle life - Sequential hydraulic tests - Fire test
Plastic liner material		- Initial pressure cycle life - Sequential hydraulic tests - Sequential pneumatic tests - Fire test
Fiber material [1]		- Initial burst, Initial pressure cycle life - Sequential hydraulic tests - Fire test
Resin material		- Initial burst, Initial pressure cycle life - Sequential hydraulic tests - Fire test
Diameter [2]	≤20%	- Initial burst, Initial pressure cycle life
	>20%	- Initial burst, Initial pressure cycle life - Sequential hydraulic tests - Fire test
Length **[8]**	≤50%	- Initial burst, Initial pressure cycle life - Fire test [3]
	>50%	- Initial burst, Initial pressure cycle life - Sequential hydraulic tests - Fire test [3]
Coating		- Sequential hydraulic tests - Fire test [4]
Boss [5]	Material, geometry, opening size	- Initial burst, Initial pressure cycle life
	Sealing (liner and/or valve interface)	- Sequential pneumatic tests
Fire protection system		- Fire test
Valve change [6]		- Sequential pneumatic tests - Fire test [7]
Container attachment	**Material, geometry**	**- Sequential pneumatic tests** **- Fire test [7]**

Notes:

1. Change of fiber type, e.g., glass to carbon is not applicable. Change of design applies only to changes of materials properties or manufacturer within a fiber type.
2. Only when thickness change is proportional to diameter change.
3. Fire test is not required, provided safety relief devices or device configuration passed the required fire test on a container with equal or greater internal water volume.
4. Fire test required if coating affects fire performance.
5. Tests are not required if the stresses in the neck are equal to the original stresses or reduced by the design change (e.g., reducing the diameter of internal threads, or changing the boss length), the liner to boss interface is not affected, and the original materials are used for boss, liner, and seals. **Boss change includes manifold change for the case of multiple permanently interconnected chambers.**
6. Alternative valve shall be approved in accordance with part II.
7. Fire test not required if TPRD design has not been changed, and the mass of the changed valve is +/- 30 per cent of the original valve.
8. **Includes change of chamber number for the case of multiple permanently interconnected chambers. "**

Insert new Annex 8, to read:

"Annex 8 – Part 1

Test procedures for evaluating the material compatibility

1. Materials definition.

1.1. The material under consideration shall be defined by a materials specification – the specification can be a nationally-recognized standard or a company-defined specification. The materials specification shall include requirements for the following:

(a) allowable compositional ranges;

(b) specified minimum tensile yield strength (Sy);

(c) specified minimum tensile strength (Su); and,

(d) specified minimum tensile elongation (El).

1.2. The material should be tested in the final product form whenever possible. When the component geometry precludes extraction of test specimens, the material may be tested in the semi-finished product form with mechanical properties that are nominally equivalent to the mechanical properties of the component.

1.3. Either the materials manufacturer's certification or equivalent testing performed in air at room temperature may be used to verify that the material meets the specification. The measured tensile strength is denoted S* (average value from at least two tests at room temperature in air or from the mill certification) and is used to define the maximum stress for fatigue testing.

1.4. Welds and metallurigically-bonded materials

(a) When materials are welded (or metallurgically-bonded) and the joint is exposed to gaseous hydrogen, weld specimens shall be tested in conjunction with the base materials for hydrogen compatibility;

(b) Welds and metallurgically-bonded materials shall be defined by a welding procedure specification (WPS) that defines the joining procedure as well as the composition and specified minimum tensile requirements (Sy, Su and El) of the joined structure (e.g., weld metal);

(c) Test specimens should be extracted from the joined structure whenever possible. Representative joints can be prepared, if test specimens cannot be extracted from the joined structure;

(d) Weld test specimens shall be measured in gaseous hydrogen and shall satisfy the requirements of the WPS as well as the testing requirements in paragraph 3 of this Annex.

2. Environmental test conditions

2.1. Gas purity

(a) The purity of the gaseous hydrogen from the testing chamber (referred to as the sampled gas) shall be verified to satisfy the requirements of applicable fuelling standards or the values in Table 1;

(b) If three consecutive tests of the sampled gas meet the oxygen and water vapor requirements in Table 1, the gas may be sampled periodically at an interval not exceeding 12 months. If the sampled gas does not meet the requirements, the test system is modified, the purging procedures are changed, or the gas sampling interval exceeds 12 months, three consecutive gas samples shall be evaluated to demonstrate that the test system and procedures meet the requirements of Table 1.

Table 1
Gaseous hydrogen purity requirements in parts per million by volume (except where noted)

Species	*Source gas requirements*	*Sampled gas requirements*
H_2	99.999 % min	–
O_2	≤ 1	< 2
H_2O	≤ 3.5	< 10
$CO + CO_2$	≤ 2	–

2.2. Pressure

Testing in gaseous hydrogen shall be performed at a minimum hydrogen pressure of 125 per cent NWP

2.3. Temperature

(a) The specimen temperature for fatigue life testing in hydrogen shall be 293 ± 5 K;

(b) The specimen temperature for slow strain rate tensile (SSRT) test in hydrogen shall be 228 ± 5 K.

3. Testing requirements

3.1. The requirements for either the notched specimen methodology (option 1) or the smooth specimen methodology (option 2) shall be satisfied. It is not necessary to satisfy both the notched and smooth methods.

3.2. Notched specimen methodology (option 1)

(a) Notched bar specimens shall be used with an elastic concentration factor (Kt) of greater than or equal to 3. A minimum of three specimens shall be tested in the environmental conditions described in paragraph 2. of this Annex.

(i) Force-controlled fatigue life tests shall be performed with a constant load cycle in accordance with internationally-recognized standards. The stress at maximum load during fatigue cycling shall be greater than or equal to 1/3 of S* (the

average tensile strength measured at room temperature in air). The stress is defined as the load divided by the net-section stress (i.e., minimum initial cross sectional area of the specimen). The load ratio (R) shall be 0.1, where R = S_{min}/S_{max} (S_{min} is the minimum net-section stress and S_{max} is the maximum net-section stress;

(ii) The frequency shall be 1 Hz or lower.

(b) Requirement for notched specimen methodology:

For notched-specimen fatigue testing, the number of applied cycles (N) shall be greater than 10^5 cycles for each tested specimen.

3.3. Smooth specimen methodology (option 2)

(a) Smooth fatigue specimens shall be used in accordance with internationally-recognized standards. A minimum of three specimens shall be tested in the environmental conditions described in paragraph 2. of this Annex.

(i) Force-controlled fatigue life tests shall be performed with a constant load cycle in accordance with internationally-recognized standards. The stress at maximum load during fatigue cycling shall be greater than or equal to 1/3 of S* (the average tensile strength measured at room temperature in air). The stress is defined as the load divided by the net-section stress (i.e., minimum initial cross sectional area of the specimen). The load ratio (R) shall be -1 (fully reversed tension-compression load cycle), where R = S_{min}/S_{max} (S_{min} is the minimum net-section stress and S_{max} is the maximum net-section stress;

(ii) The frequency shall be 1 Hz or lower.

(b) Slow strain rate tensile (SSRT) test specimens shall be used in accordance with internationally-recognized standards. A minimum of three specimens shall be tested in the environmental conditions described in paragraph 2. of this Annex.

a. Displacement during the test shall be measured on the specimen over a conventional gauge length (≥ 12 mm and 3-5 times the diameter of the specimen). Normally, this is an extensometer attached directly to the specimen, but other equivalent methods are acceptable. The measured strain rate (between the yield force and the maximum force) shall be ≤ 5 x 10^{-5} s^{-1}.

(c) Requirements for smooth specimen methodology:

For smooth-specimen fatigue testing, the number of applied cycles (N) shall be greater than 2 x 10^5 cycles for each tested specimen.

For SSRT testing, the measured yield strength shall be greater than 80 per cent of the yield strength measured in air at the temperature defined in paragraph 2. of this Annex.

[Annex 8 – Part 2

Humid gas stress corrosion cracking test

1. Materials definition

1.1. This test applies to wrought aluminium alloy products.

1.2. The material under consideration shall be defined by a materials specification – the specification can be a nationally-recognized standard or a company-defined specification. The materials specification shall include requirements for the following:

(a) Allowable compositional ranges

(b) Specified minimum yield strength, Sy

(c) Specified minimum tensile strength, Su

(d) Specified minimum tensile elongation, El

1.3. Either the materials manufacturer's certification or equivalent testing performed in air at room temperature may be used to verify that the material meets the specification. The measured 0.2 per cent proof stress is denoted σ0.2 (average value from two specimens measured at room temperature in accordance with the procedures given in ISO 6892-1:2019) and is used for introducing fatigue pre-crack.

2. Environmental test conditions and duration

2.1. Temperature: 298 ± 5 K for the entire duration of the test.

2.2. Atmosphere and humidity: no generation of dew in air measuring 85 per cent of higher in relative humidity for the entire duration of the test.

2.3. Test period: 90 days (in accordance with B6.6 of ISO 7866:2012).

3. Testing requirements

3.1. Test specimen: One of the specimen geometries, or a combination of them, shall be used for test:

(a) Compact specimen of ISO 7539-6:2011;

(b) Single edge bend specimen (SE specimen or cantilever bend specimen of ISO 7539-6:2011);

(c) Double-cantilever-beam specimen (DCB specimen) of ISO 7539-6:2011;

(d) Modified wedge-opening-load-specimen (modified WOL specimen) of ISO 7539-6:2011 ;

(e) C-shaped specimen of ISO 7539-6:2011.

3.2. Specimen orientation: the orientation of specimen sampling shall be the Y-X orientation. Other orientation may be added when necessary.

3.3. Fatigue pre-crack shall be introduced in accordance with class 6 of ISO 7539-6:2018.

3.4. A load is applied under constant load or constant displacement conditions.

(a) For the constant load condition, it is necessary to use a testing machine capable of load accuracy control within ±1 per cent of the load applied, as defined in 7.6.3 of ISO 7539-6:2011.

(b) For the constant displacement condition, the sensitivity of the displacement gauge shall be not less than 20 mV/mm as to minimize the excess amplification of small signals. The linearity of the gauge is such that the deviation from the true displacements shall not exceed 3µm (0.003 mm) for smaller displacements up to 0.5 mm and not exceed 1 per cent of recorded values for larger displacements. These conditions are in accordance with 7.5.3 of ISO 7539-6:2011.

(c) The load is the value of K_{IAPP} obtained by the following equation from B.6.2 of ISO 7866:2012.

$$K_{IAPP} = 0.056\sigma_{0.2}$$

3.5. Measurement of load: For constant displacement condition, the load shall be measured by one of the following methods after the 90-day test period.

(a) When the load is not monitored:

(i) At the end of the test, the crack mouth opening displacement is measured before removal of the load.

(ii) The load is removed.

(iii) The load is reapplied until the crack mouth opening displacement attains the value in (1) with a load measuring instrument.

(b) When the load is monitored, the load at the end of the test is measured. It is also acceptable to calculate the load value from the values of elastic strain measured between the start and the end of the test.

3.6. Fatigue post-cracking and breaking shall be introduced as follows:

(a) For a constant load condition, a fatigue post-crack is introduced until the post-crack length is extended to 1 mm or more by applying a fatigue load equivalent to a stress intensity factor not exceeding 0.6 times the value of K_I obtained by loading.

(b) For a constant displacement condition, after the load measurement is performed per (e) above, the load is removed and a fatigue post-crack is introduced until the post-crack length is extended to 1 mm or more by applying a fatigue load equivalent to a stress intensity factor not exceeding 0.6 times the value of K_I obtained in (e) above.

After the introduction of a fatigue post-crack the specimen shall be broken open. If it is possible to identify the HG-SCC fracture surface, the specimen may be broken by a method other than the introduction of a fatigue post-crack

3.7. Measurement of crack length: After breaking of the specimen, the following aspects of crack length shall be measured using a scanning electron microscope (SEM) or other measuring instruments with an accuracy within ±0.01 mm:

(a) effective crack length including the fatigue pre-crack, a_{pre};

(b) effective crack length up to the tip of the HG-SCC crack, a_{scc};

Three measurements shall be taken from the direction perpendicular to the broken surface at 25 per cent, 50 per cent and 75 per cent of the specimen thickness, and the average value of the measurements at these 3 points is selected as the effective crack length of a_{pre} or a_{scc}.

4. Validity of test

4.1. Fatigue pre-crack: Of the apre values measured at locations of 25 per cent, 50 per cent and 75 per cent of the specimen thickness, it shall be verified that the difference between the largest and smallest values does not exceed 5per cent of net specimen width W.

4.2. Small scale yielding and plane strain condition: It shall be verified that a, (W-a) and B (specimen thickness) satisfy the following equation as specified in B6.7 of ISO 7866:2012:

$$a, (W\text{-}a), B \geqq 1270\ (K_I / \sigma_{0.2})^2$$

Where a, $(W\text{-}a)$ and K_I are as follows:

(a) For constant load condition: $a = a_{scc}$

$(W\text{-}a) = (W\text{-}\ a_{scc})$

$K_I = K_{IAPP}$

(b) For constant displacement condition: $a = a_{pre}$

$(W\text{-}a) = (W\text{-}\ a_{pre})$

$K_I = K_{IAPP}$

4.5. If the test conditions in (a) and (b) above are not satisfied, the test is invalid.

5. Acceptance Criterion

The applicability of materials shall be judged as follows:

5.1. The crack extension (ascc - apre) by HG-SCC in paragraph 4.2. of this Annex is examined to determine if it exceeds 0.16 mm.

5.2. The actual applied value of K_{IAPP}, defined as K_{IA}, is calculated by using apre and the load applied according to paragraph 3.4.(a) for constant-load condition and paragraph 3.4.(b) for constant-displacement condition.

5.3. The validity of materials is judged as per Table 1 below.

Table1
Qualification of materials

Case	*Crack extension*	K_{IA} versus K_{IAPP}	Judgment*
I	$(a_{scc} - a_{pre}) \leqq 0.16$ mm	$K_{IA} \geqq K_{IAPP}$	Pass
II		$K_{IA} < K_{IAPP}$	Invalid
III	$(a_{scc} - a_{pre}) > 0.16$ mm	$K_{IA} \leqq K_{IAPP}$	Fail
IV		$K_{IA} > K_{IAPP}$	Invalid

* Material shall be judged as follows:

Pass: Materials that satisfy this requirement are judged to have applicable resistance to HG-SCC for compressed hydrogen containers as specified in B.7.3 of ISO 7866:2012.

Fail: Materials are judged to be failed for application for compressed hydrogen containers.

Invalid: Materials cannot be judged in these conditions.

In case II, another test is recommended if K_{IA} equals to K_{IAPP} or is in some degree greater than K_{IAPP}.

In case IV, where K_{IA} is considerably greater than K_{IAPP}, another test is recommended because materials may pass if K_{IA} is a little greater than K_{IAPP}.

5.4. **A minimum of three valid specimens shall meet the "passed" judgment in this test.** "]

II. Justification

1. The proposal for the amendment 1 to Global Technical Regulation No.13 (ECE/TRANS/WP.29/GRSP/2022/16) has been submitted to the 72nd session. This proposal contains numbers of improvements to the original GTR to promote technical harmonisation and to achieve enhanced reproducibility and reproducibility of the test requirements, higher clarity and consistency, adaptation to technical progress, and so on.

2. Some of the Contracting Parties to the 58 Agreement and industry organizations (OICA, CLEPA) foresee the benefit for transposing the amended technical requirements of GTR13 into UN Regulations as early as possible in order to support earlier and broader expansion FCV market that is ne of the key enabler for carbon neutral society.

3. Technical requirements in this proposal are copied from the Amendment 1 of GTR13, while additional elements such as material compatibility and geometrical requirements of refuelling receptacle as described in the Part I of GTR13 are also included in order to achieve complete reciprocal recognition of the approval between the European Union and Japan.

4. Where options are provided in GTR13 for the implementation into regional or national requirements, the appropriate options have been adopted in this proposal.

5. Paragraph 5.1.: [Installation of remotely located additional TPRDs is allowed as long as the mechanical integrity and durability of the supply lines are demonstrated, based on the following test matrix:

1. CHSS including remote TPRDs and their supply lines:

    a. On road stresses and usages as described in qualification tests of §5.3

    b. Fire test of §5.4

2. Remote TPRDs and their supply lines

    a. The qualification tests described in § 6.1 (pressure cycling, temperature cycling, salt corrosion resistance, vehicle environment, accelerated life, stress corrosion cracking for copper-based alloys and atmospheric exposure for non-metallic pieces), except the drop and vibration test which will apply only to the remote TRPDs

3. The risk related to vibration loads

At component level the additional TPRDs are submitted to drop and vibration test in §6.1g. The performance of the core and the glass part of the TPRDs is assessed to qualify the performance of the closure.

The regulation does not define vibration tests at vehicle level. This criterion is handled by the manufacturer for each vehicle as the vibration load path is dependent on multiple parameters (vehicle structure, suspension, location and type of fixation of the CHSS ….)

4. The crash/impact loads related to the integration of the CHSS on the vehicle are addressed in §7.2, where the integrity of the CHSS including remote TPRDs and supply lines is assessed]

6. Paragraph 5.1.1.: BPmin of 200 per cent NWP is applied also for the containers of 35 MPa or less.

7. Paragraph 5.1.2.: 11,000 cycles for no leakage are required for all categories of vehicles as decided for the original version of this Regulation. In GTR13, the new assessment shows that 11,000 cycles will sufficiently represent a 25-year service life. Therefore, the extrapolated number of 15,000 cycles for a 20-year service life in the current Regulation is deleted.

8. Paragraph 5.5.: The technical requirements for material compatibility for CHSS are based on those prescribed in clauses M and N of the GTR13 Part I. Because the limited numbers of test laboratories can currently carry out these material tests, the compliance to this requirement will be determined based on the technical documentation provided by the manufacturer. The requirements of non-metallic materials are not fully addressed at the informal working group or GTR13 phase 2 and therefore existing requirements of the European Union (Regulation (EU) 2021/535, Annex XIV) are introduced for this Regulation. For such documentation, manufacturer may utilize scientific publications provided by an acknowledged bodies as applicable or obtain own test reports.

9. Paragraph 6.3.: The technical requirements for material compatibility for specific components, i.e. primary closure devices, are based on those prescribed in clauses M and N of the GTR13 Part I with the similar certification procedure as CHSS. However, non-plastic materials for such specific components are not specifically required because non-metallic materials are subject to atmospheric exposure test adopted in this proposal. For such documentation, manufacturer may utilize scientific publications provided by an acknowledged bodies as applicable or obtain own test reports. [With this amendment, the tests of specific components may be carried out with either hydrogen or non-reactive gas. If the tests are conducted with hydrogen, the material compatibility in Annex 8, part 1 is deemed to be satisfied since the test with hydrogen ensure the life-time performance under the exposure to hydrogen.]

10. Paragraph 7.2.: In GTR13, the crash test procedure itself is not specified and therefore current versions of UN Regulation 134 apply frontal impact test procedure of UN Regulation No. 12 or UN Regulation No.94 and lateral impact test procedure for UN Regulation No.95. Since Un Regulation No.137 for full-wrap frontal impact has been adopted and applied in most of the Contracting Parties to the 58 Agreement, Both UN Regulation No.94 and UN Regulation No.137 are required to the extent where the Regulations apply as prescribed in their scope. [Further, in parallel to this proposal, the proposals to amend those crash regulations are submitted to include post crash integrity of hydrogen system and with assumption of the adoption of these amendments, the approval according to these UN Regulations may be treated as the alternative to certify the post-crash performance.]

11. Paragraph 7.2.: For vehicles where the crash regulations do not apply, sled tests have been introduced in this Regulation. In this proposal, the shape of acceleration pulse is defined in order to ensure the repeatability and reproducibility of the tests in similar manner as the UN Regulation No.100.

12. Paragraph 7.2.4.: For vehicles not subject to crash tests, geometric distance requirements have been included in this Regulation. In this proposal, the application of such distance requirements are changed from container to primary closure devices because these are considered more vulnerable in the crash situations. [The alternative lateral impact test in paragraph 7.2.4.3. may be applied for vehicles with CHSS installed at the height of MDB (i.e at a 800 mm height from the ground). For installation above 800 mm, the distance requirements are maintained as we need further investigations are needed to define a specific test procedure addressing a realistic crash configuration.]

13. Paragraph 9.: Following the Revision 3 of the 58 Agreement, the reference of the general requirements of the procedure for conformity of production is adapted. [With reference to the Schedule 1 of the 58 Agreement, the general provisions in former paragraphs 9.1. and 9.2. are considered as redundant. The specific requirements for CHSS prescribed in former paragraph 9.3. are thoroughly reviewed and amended with the light of future increase of the production volume of the CHSS in the market.]

14. Paragraph 15.: Since the type-approval of hydrogen fuelled vehicles according to this Regulation require three stages of type approvals mostly by different manufacturers, i.e. Part II approval for primary closure devices, Part I approval for CHSS and Part III approval for vehicles. These processes may need to be taken in series where some of the tests require considerable duration to conduct. Accordingly, there should be sufficient time provided before the mandatory application of the proposed amendments after the entry into force. In addition, the number of hydrogen-fuelled vehicles approved in accordance with existing versions of Regulation No.134 will be limited and therefore the application of this amendment for existing types will make little sense. Considering above, the application for new type approval from September 1st [2027] is proposed without having the application to vehicle, system and components approved in accordance with existing versions of this Regulation.